FIG.1

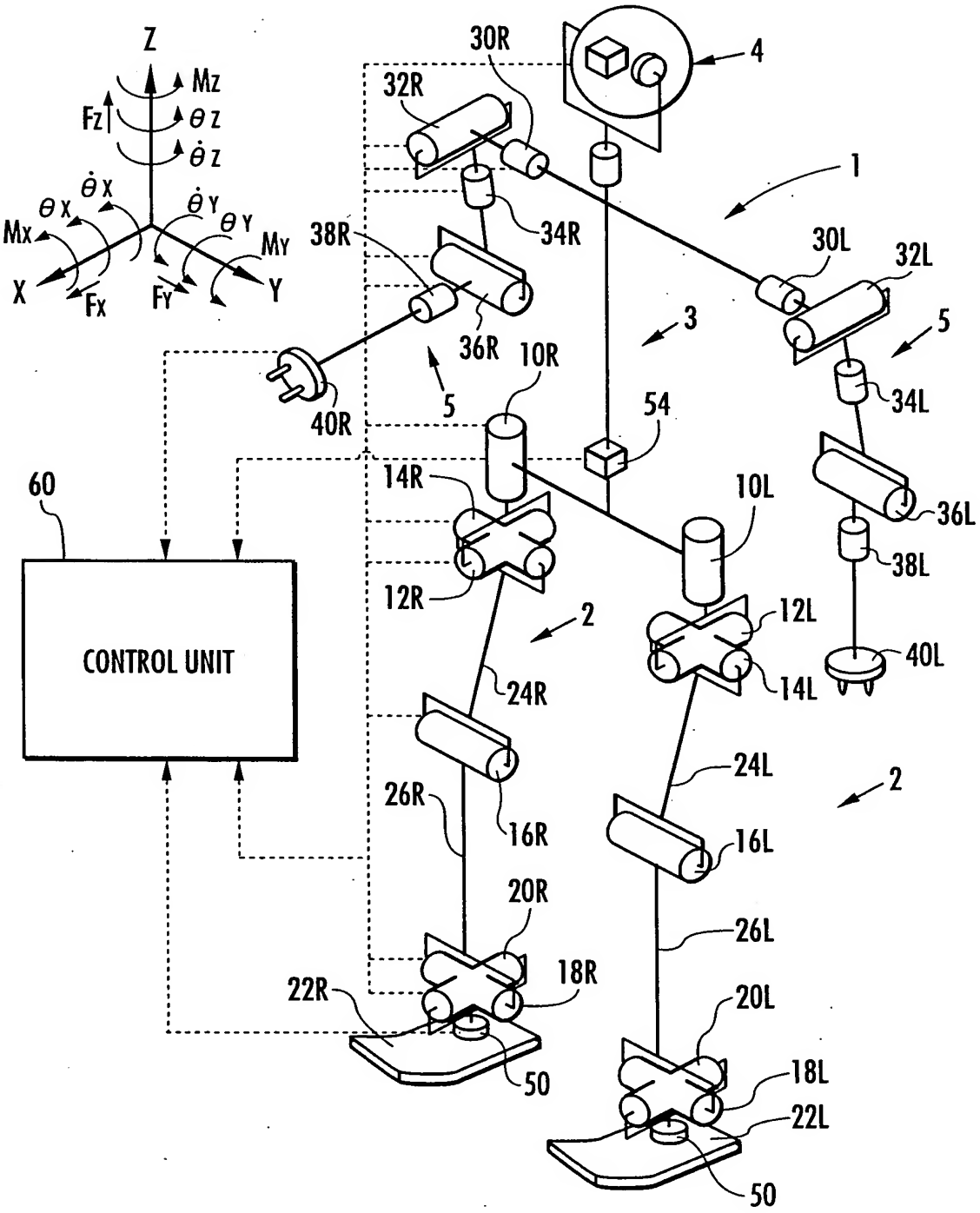

Z
Mz
Fz
θz
θ̇z
θ̇x
θx
θ̇y
θy
Mx
My
X
Fx
Fy
Y
30R
32R
4
1
34R
38R
30L
32L
3
5
36R
10R
5
54
34L
40R
14R
10L
36L
60
38L
12R
2
12L
40L
CONTROL UNIT
24R
14L
24L
2
26R
16R
16L
20R
26L
18R
22R
20L
18L
22L
50
50

FIG.2

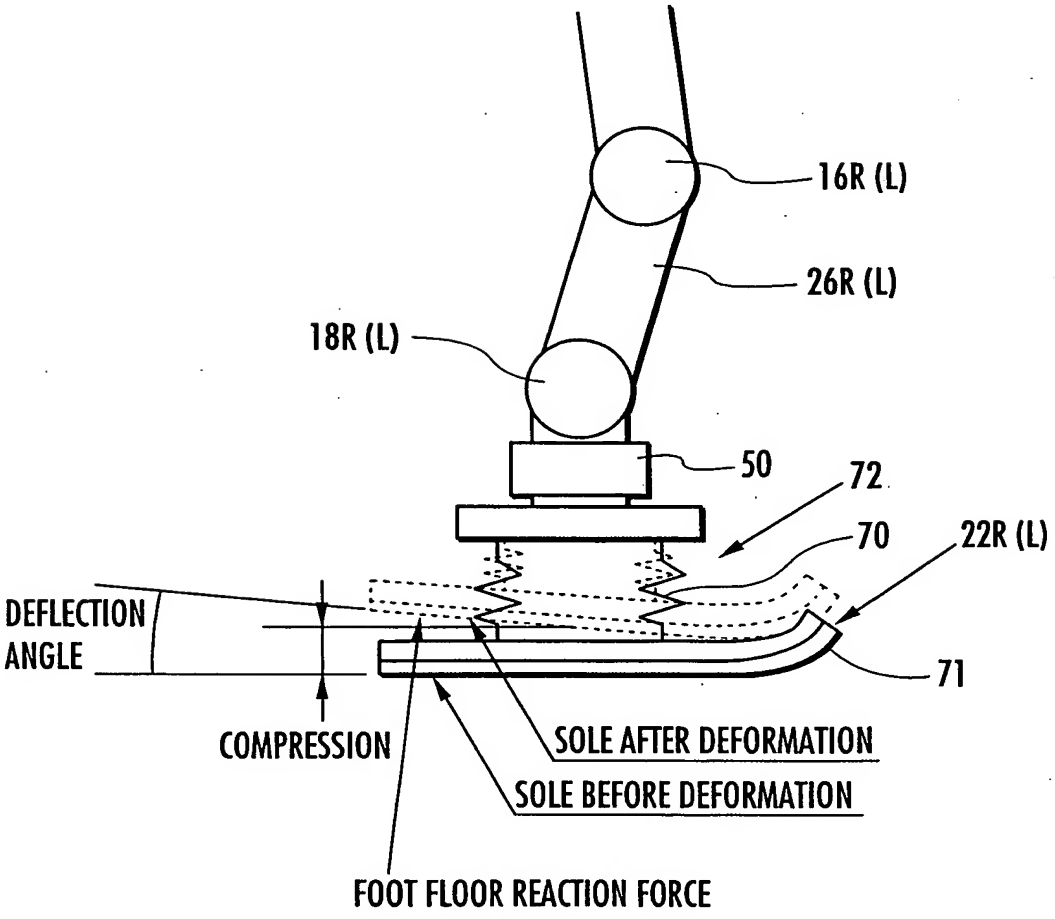
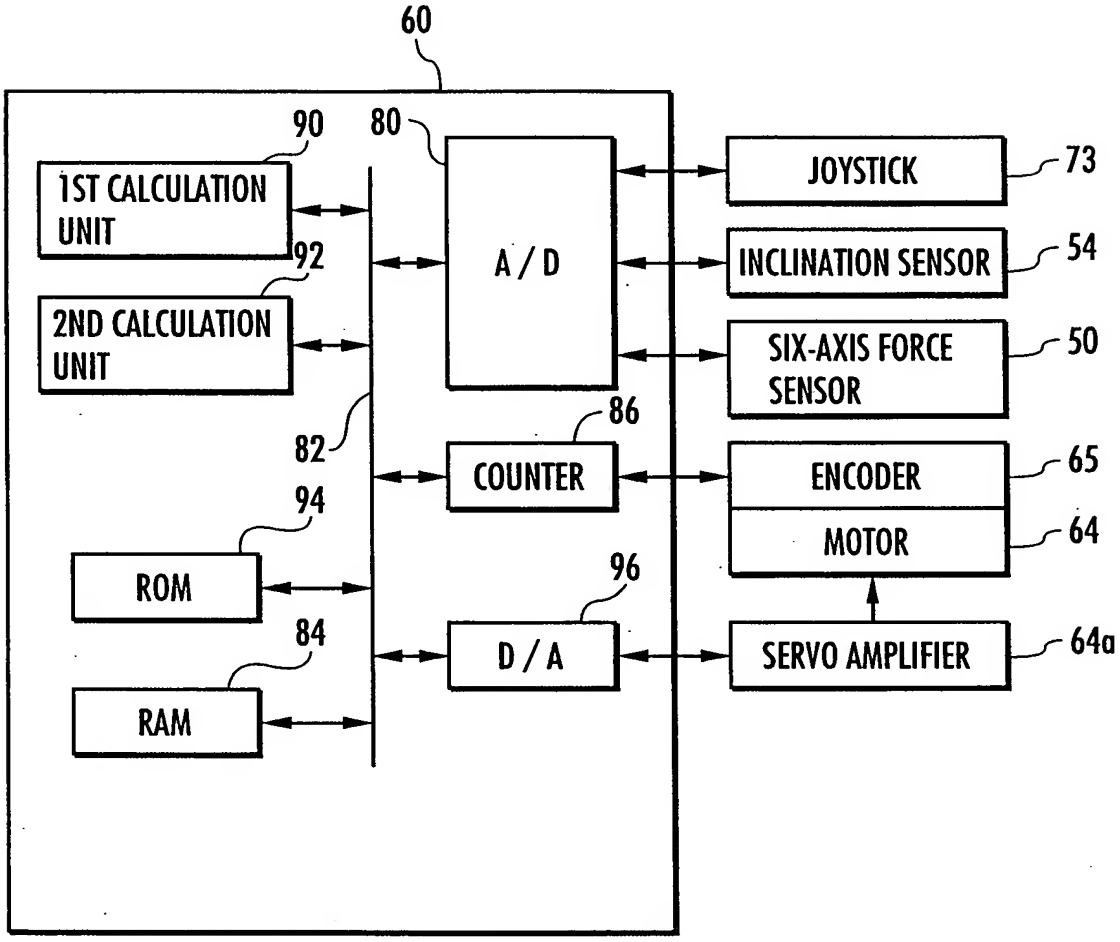

16R (L)
26R (L)
18R (L)
50
72
70
22R (L)
71
DEFLECTION ANGLE
COMPRESSION
SOLE AFTER DEFORMATION
SOLE BEFORE DEFORMATION
FOOT FLOOR REACTION FORCE

FIG.3


60
90
80
1ST CALCULATION UNIT
92
2ND CALCULATION UNIT
A / D
JOYSTICK
73
INCLINATION SENSOR
54
SIX-AXIS FORCE SENSOR
50
82
86
COUNTER
ENCODER
65
MOTOR
64
94
ROM
96
84
RAM
D / A
SERVO AMPLIFIER
64a

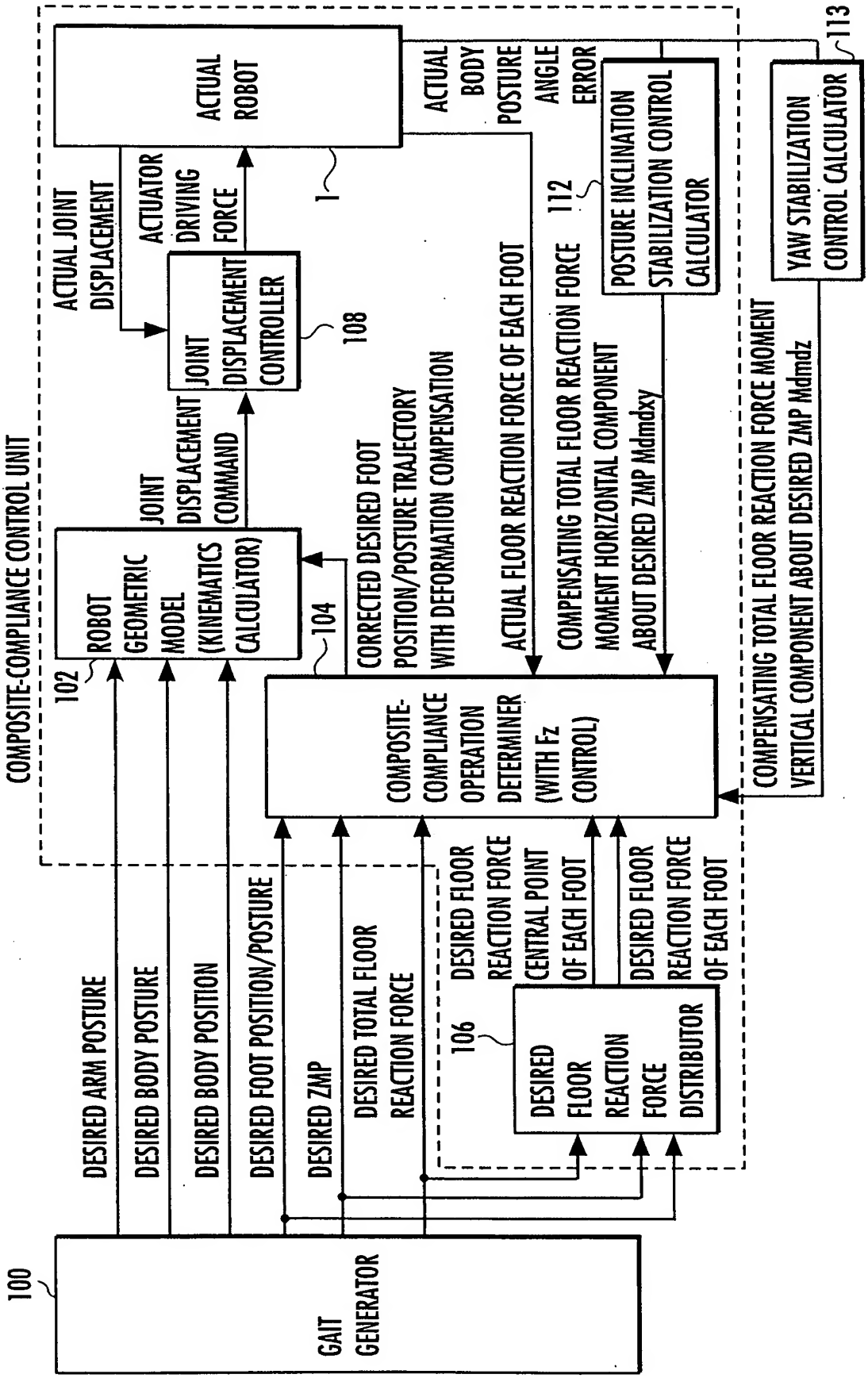

COMPOSITE-COMPLIANCE CONTROL UNIT
GAIT GENERATOR
100
DESIRED ARM POSTURE
DESIRED BODY POSTURE
DESIRED BODY POSITION
DESIRED FOOT POSITION/POSTURE
DESIRED ZMP
DESIRED TOTAL FLOOR REACTION FORCE
ROBOT GEOMETRIC MODEL (KINEMATICS CALCULATOR)
102
JOINT DISPLACEMENT COMMAND
CORRECTED DESIRED FOOT POSITION/POSTURE TRAJECTORY WITH DEFORMATION COMPENSATION
104
COMPOSITE-COMPLIANCE OPERATION DETERMINER (WITH Fz CONTROL)
ACTUAL FLOOR REACTION FORCE OF EACH FOOT
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT ABOUT DESIRED ZMP Mdmdxy
DESIRED FLOOR REACTION FORCE CENTRAL POINT OF EACH FOOT
DESIRED FLOOR REACTION FORCE OF EACH FOOT
106
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
JOINT DISPLACEMENT CONTROLLER
108
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
ACTUAL ROBOT
1
ACTUAL BODY POSTURE ANGLE ERROR
POSTURE INCLINATION STABILIZATION CONTROL CALCULATOR
112
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT ABOUT DESIRED ZMP Mdmdz
YAW STABILIZATION CONTROL CALCULATOR
113

FIG.4

FIG.5

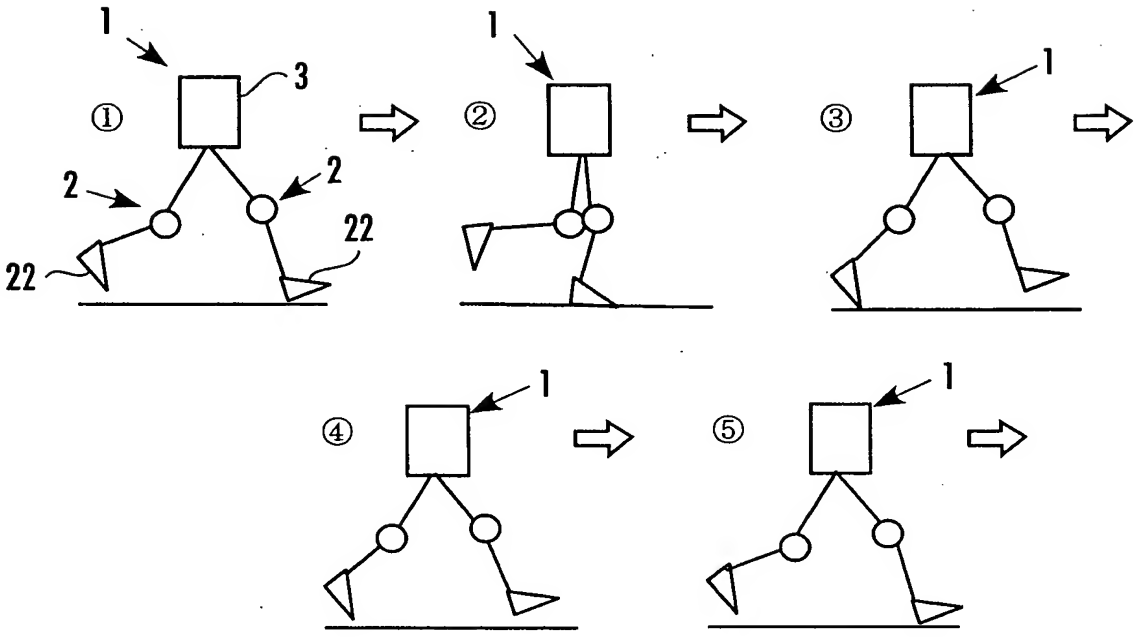


FIG.6

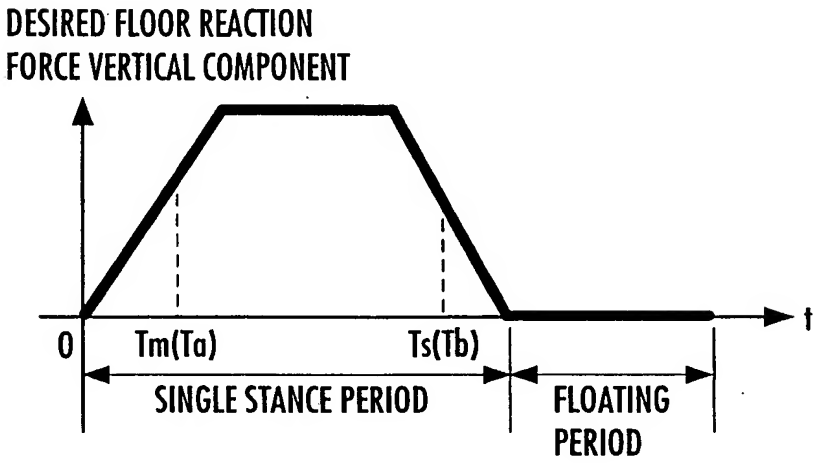

DESIRED FLOOR REACTION
FORCE VERTICAL COMPONENT
t
0
Tm(Ta)
Ts(Tb)
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.7

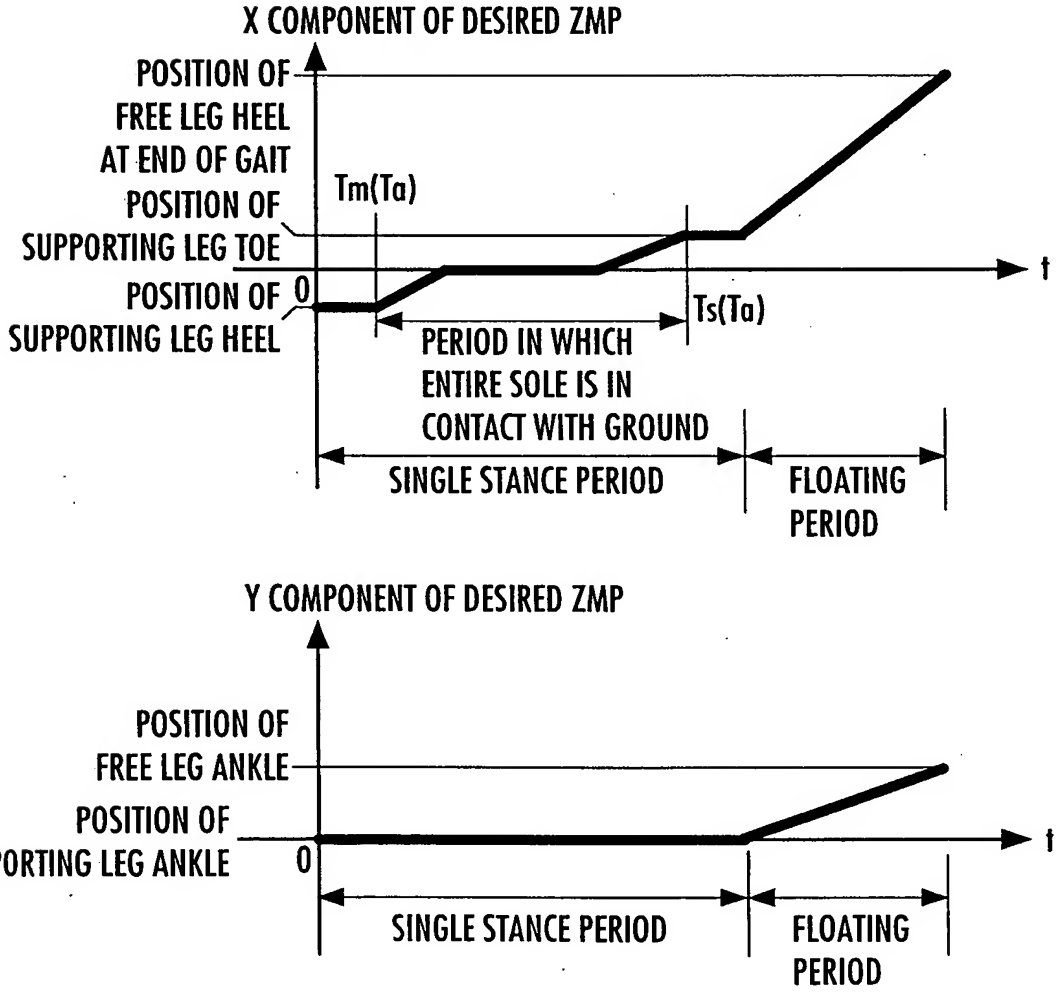

X COMPONENT OF DESIRED ZMP
POSITION OF
FREE LEG HEEL
AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
0
Tm(Ta)
Ts(Ta)
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD
Y COMPONENT OF DESIRED ZMP
POSITION OF
FREE LEG ANKLE
POSITION OF
SUPPORTING LEG ANKLE
0
t
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.8

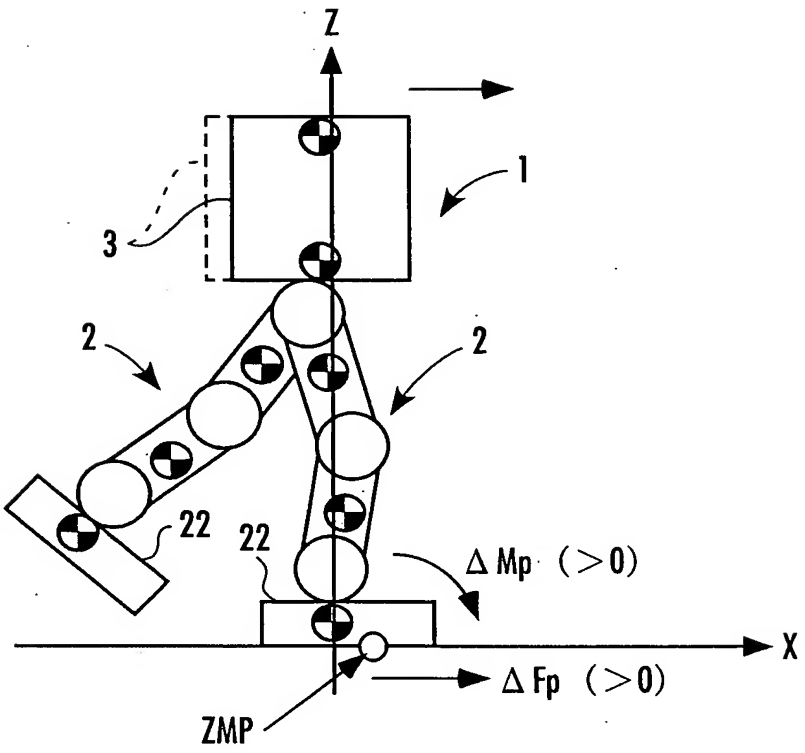


FIG.9

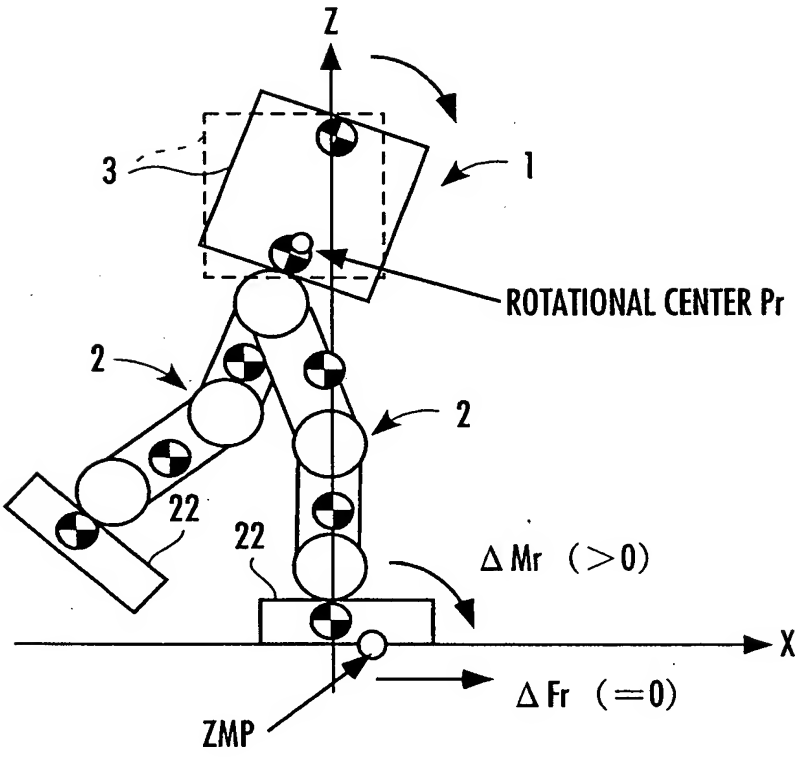


FIG.10

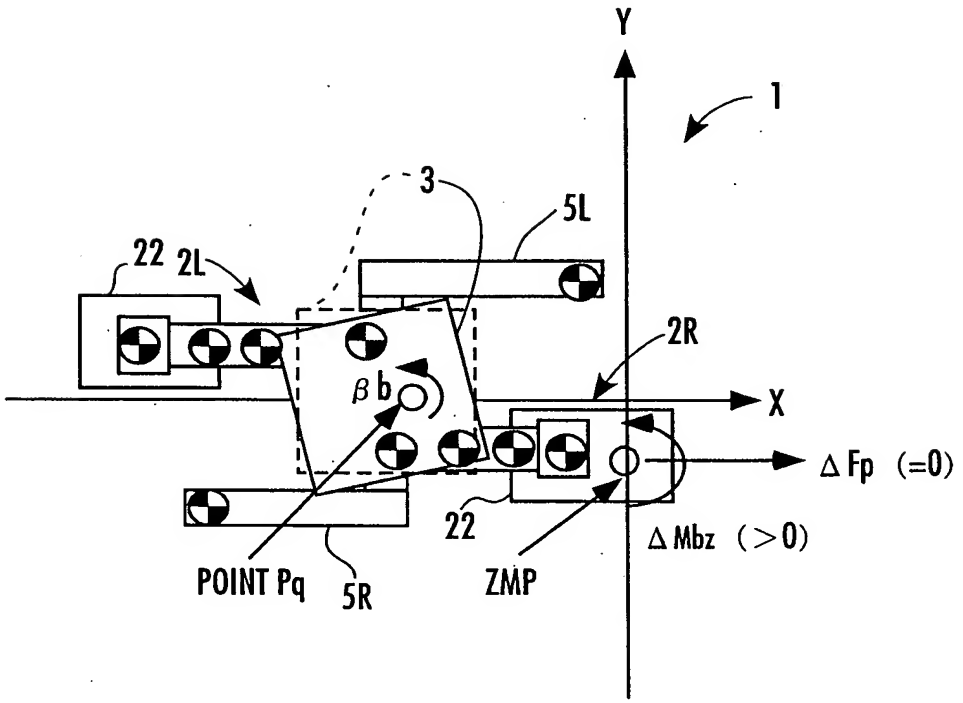


FIG.11(a)

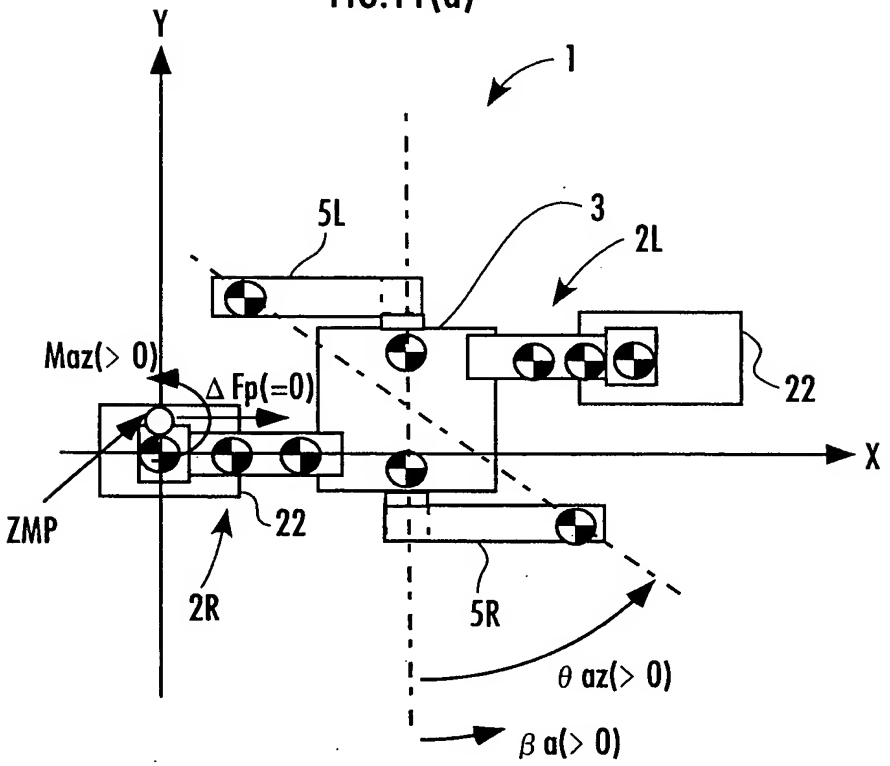



FIG.11(b)

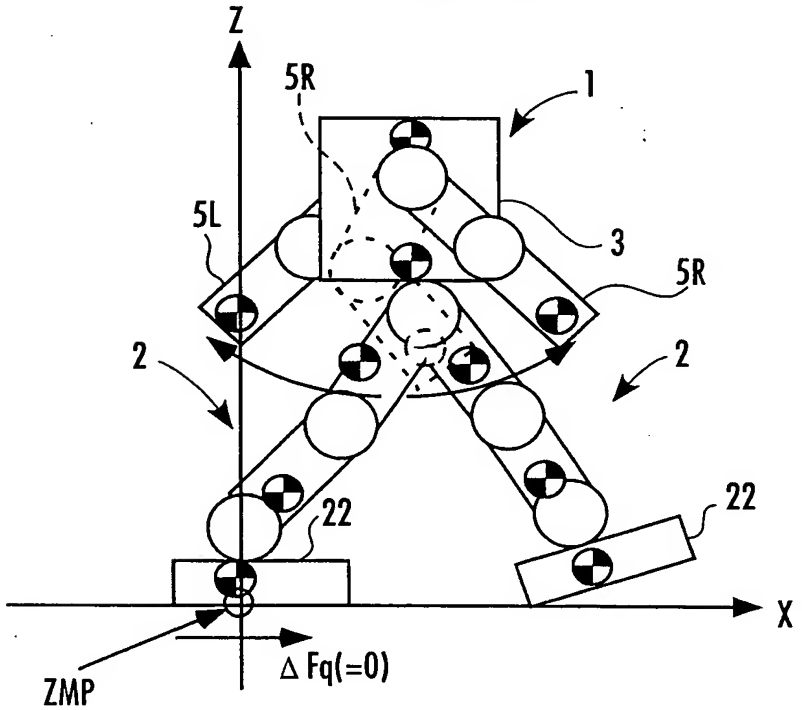


FIG.12

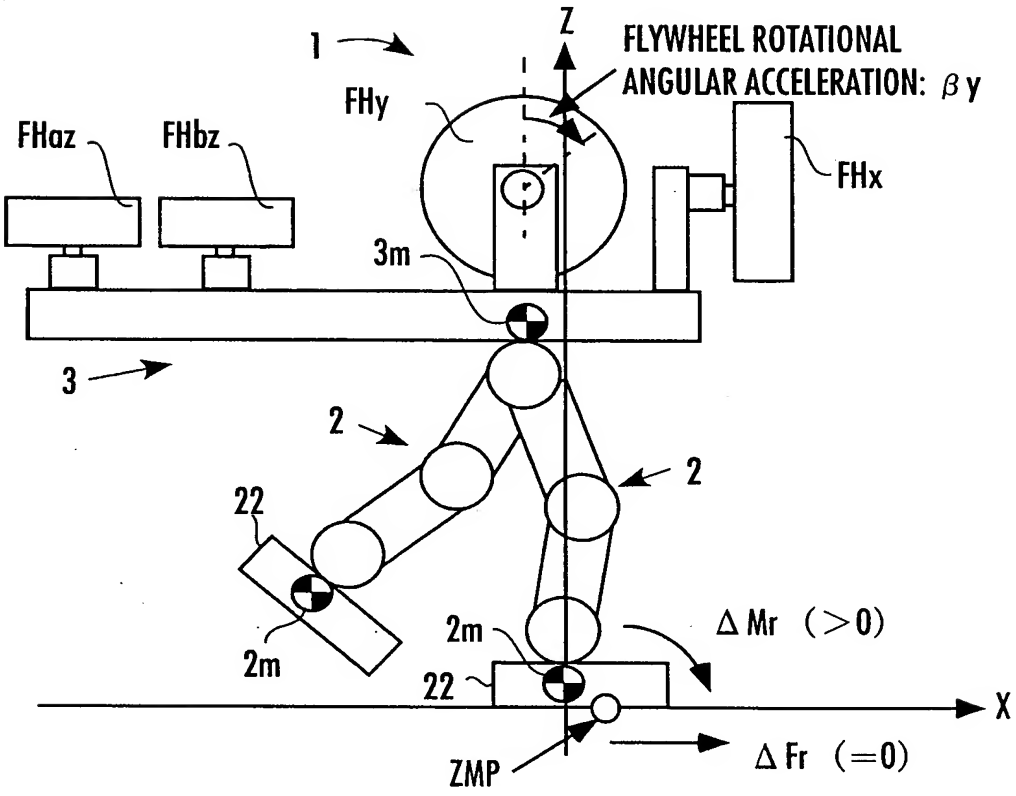

1
Z
FLYWHEEL ROTATIONAL ANGULAR ACCELERATION: βy
FHy
FHaz
FHbz
FHx
3m
3
2
2
22
2m
2m
22
ΔMr (>0)
X
ZMP
ΔFr (=0)

FIG.13

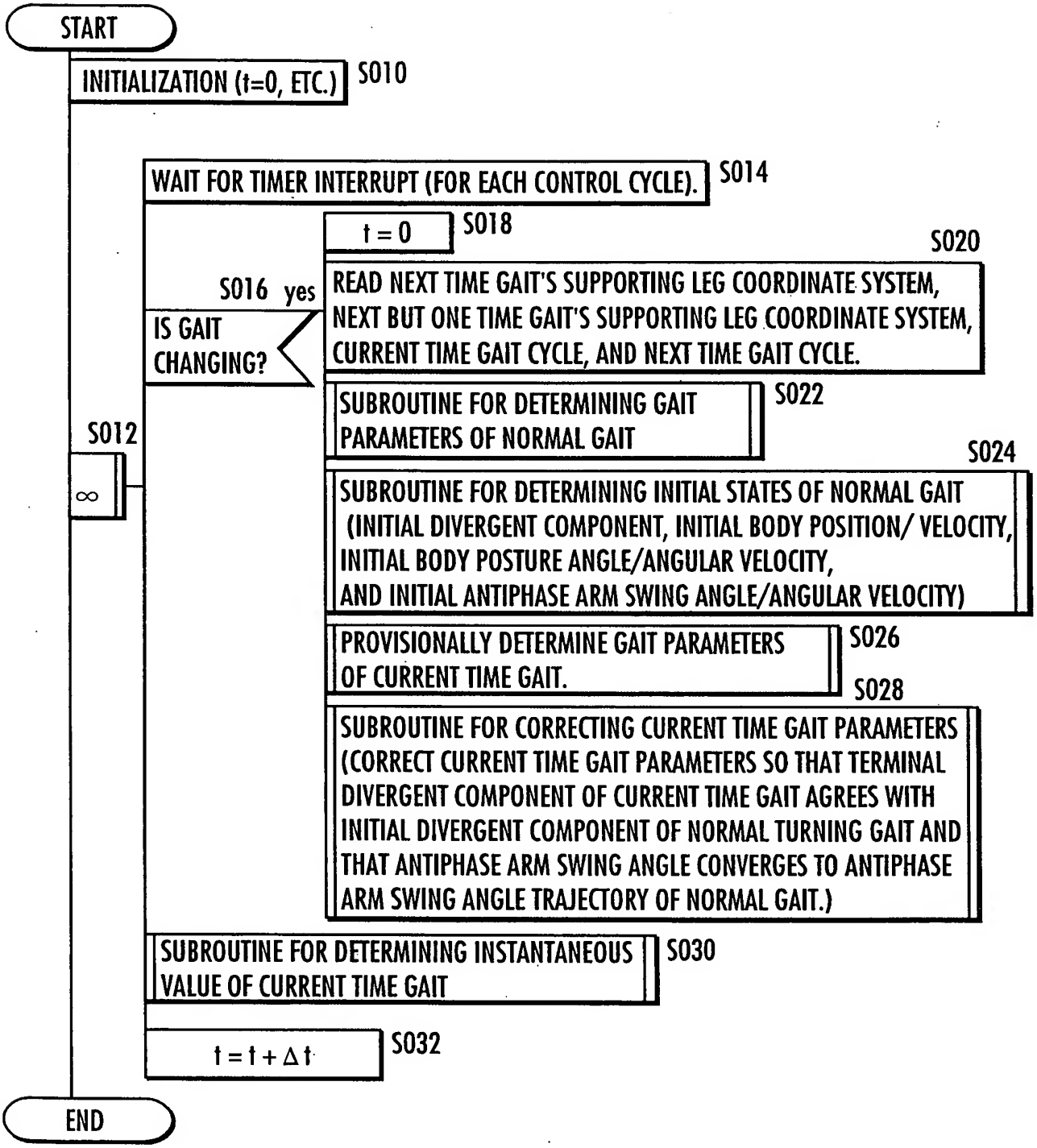

START
INITIALIZATION (t=0, ETC.)
S010
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE).
S014
t = 0
S018
S020
S016 yes
IS GAIT CHANGING?
READ NEXT TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, NEXT BUT ONE TIME GAIT'S SUPPORTING LEG COORDINATE SYSTEM, CURRENT TIME GAIT CYCLE, AND NEXT TIME GAIT CYCLE.
SUBROUTINE FOR DETERMINING GAIT PARAMETERS OF NORMAL GAIT
S022
S012
∞
S024
SUBROUTINE FOR DETERMINING INITIAL STATES OF NORMAL GAIT (INITIAL DIVERGENT COMPONENT, INITIAL BODY POSITION/ VELOCITY, INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY, AND INITIAL ANTIPHASE ARM SWING ANGLE/ANGULAR VELOCITY)
PROVISIONALLY DETERMINE GAIT PARAMETERS OF CURRENT TIME GAIT.
S026
S028
SUBROUTINE FOR CORRECTING CURRENT TIME GAIT PARAMETERS (CORRECT CURRENT TIME GAIT PARAMETERS SO THAT TERMINAL DIVERGENT COMPONENT OF CURRENT TIME GAIT AGREES WITH INITIAL DIVERGENT COMPONENT OF NORMAL TURNING GAIT AND THAT ANTIPHASE ARM SWING ANGLE CONVERGES TO ANTIPHASE ARM SWING ANGLE TRAJECTORY OF NORMAL GAIT.)
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT
S030
t = t + Δt
S032
END

FIG.14

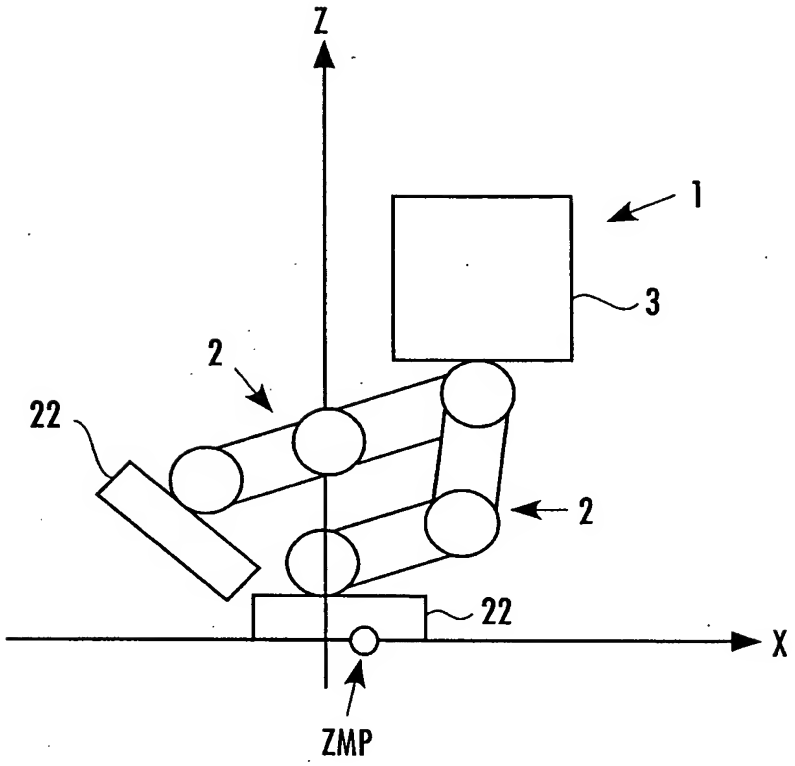


FIG.15

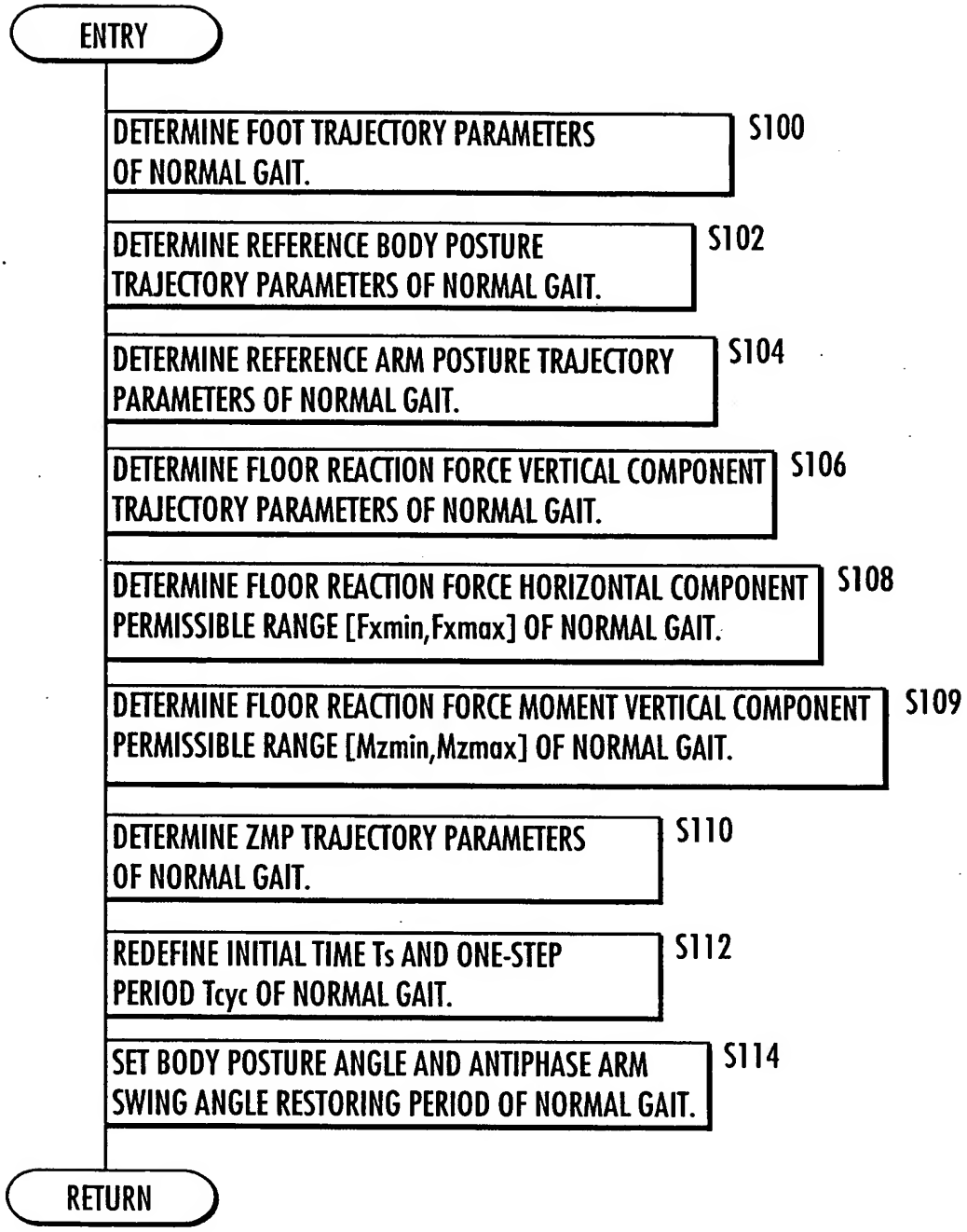

ENTRY
DETERMINE FOOT TRAJECTORY PARAMETERS OF NORMAL GAIT.
S100
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETERS OF NORMAL GAIT.
S102
DETERMINE REFERENCE ARM POSTURE TRAJECTORY PARAMETERS OF NORMAL GAIT.
S104
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETERS OF NORMAL GAIT.
S106
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF NORMAL GAIT.
S108
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] OF NORMAL GAIT.
S109
DETERMINE ZMP TRAJECTORY PARAMETERS OF NORMAL GAIT.
S110
REDEFINE INITIAL TIME Ts AND ONE-STEP PERIOD Tcyc OF NORMAL GAIT.
S112
SET BODY POSTURE ANGLE AND ANTIPHASE ARM SWING ANGLE RESTORING PERIOD OF NORMAL GAIT.
S114
RETURN

FIG.16

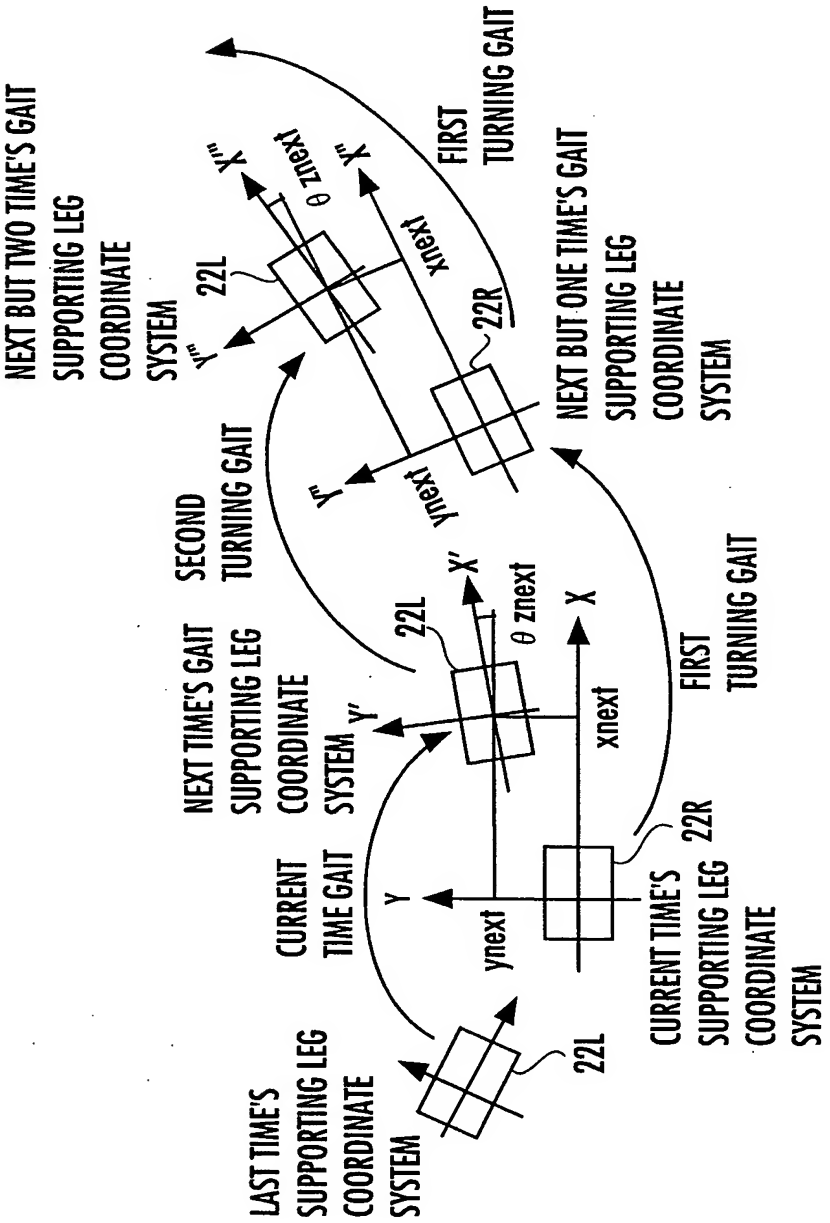

NEXT BUT TWO TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
SECOND TURNING GAIT
FIRST TURNING GAIT
NEXT BUT ONE TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
NEXT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
CURRENT TIME GAIT
CURRENT TIME'S SUPPORTING LEG COORDINATE SYSTEM
LAST TIME'S SUPPORTING LEG COORDINATE SYSTEM
22L
22R
X
Y
X'
Y'
X''
Y''
X'''
Y'''
xnext
ynext
θ znext

FIG.17

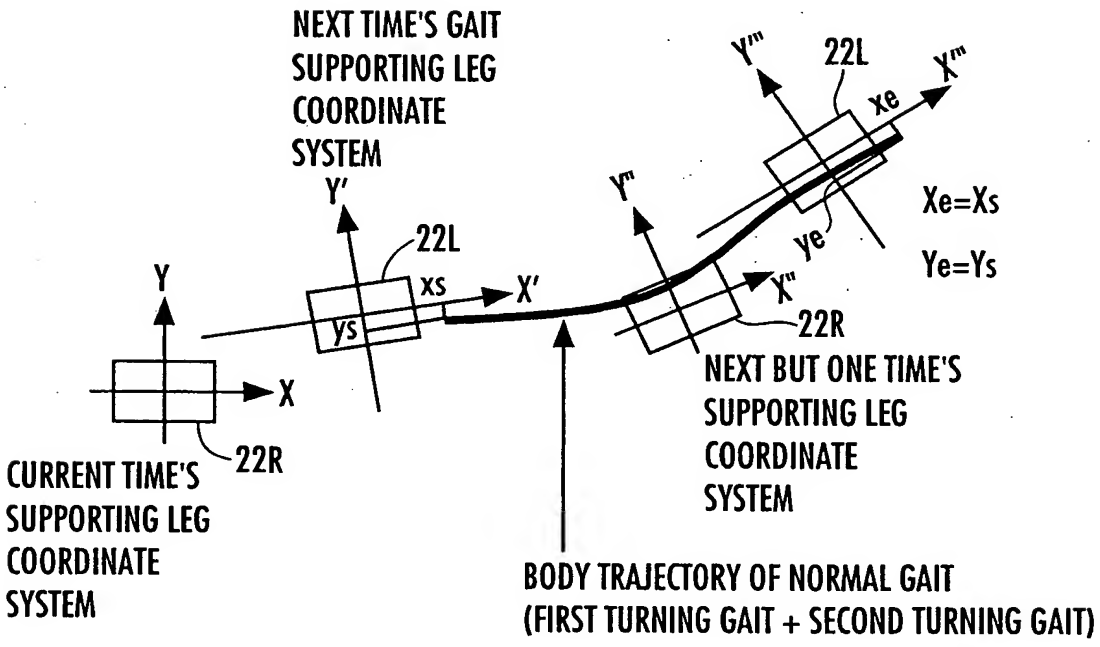

NEXT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM
Y'
22L
xs
ys
X'
Y
X
22R
CURRENT TIME'S SUPPORTING LEG COORDINATE SYSTEM
Y"
X"
22R
NEXT BUT ONE TIME'S SUPPORTING LEG COORDINATE SYSTEM
Y'"
22L
xe
ye
X'"
Xe=Xs
Ye=Ys
BODY TRAJECTORY OF NORMAL GAIT
(FIRST TURNING GAIT + SECOND TURNING GAIT)

FIG.18

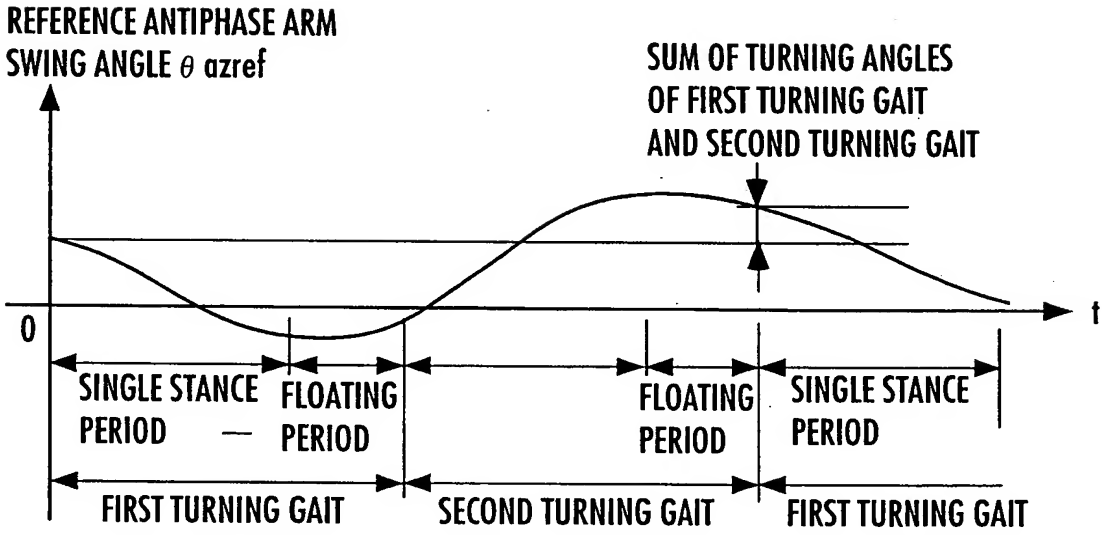

REFERENCE ANTIPHASE ARM SWING ANGLE θ azref
SUM OF TURNING ANGLES OF FIRST TURNING GAIT AND SECOND TURNING GAIT
0
t
SINGLE STANCE PERIOD
FLOATING PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT

FIG.19

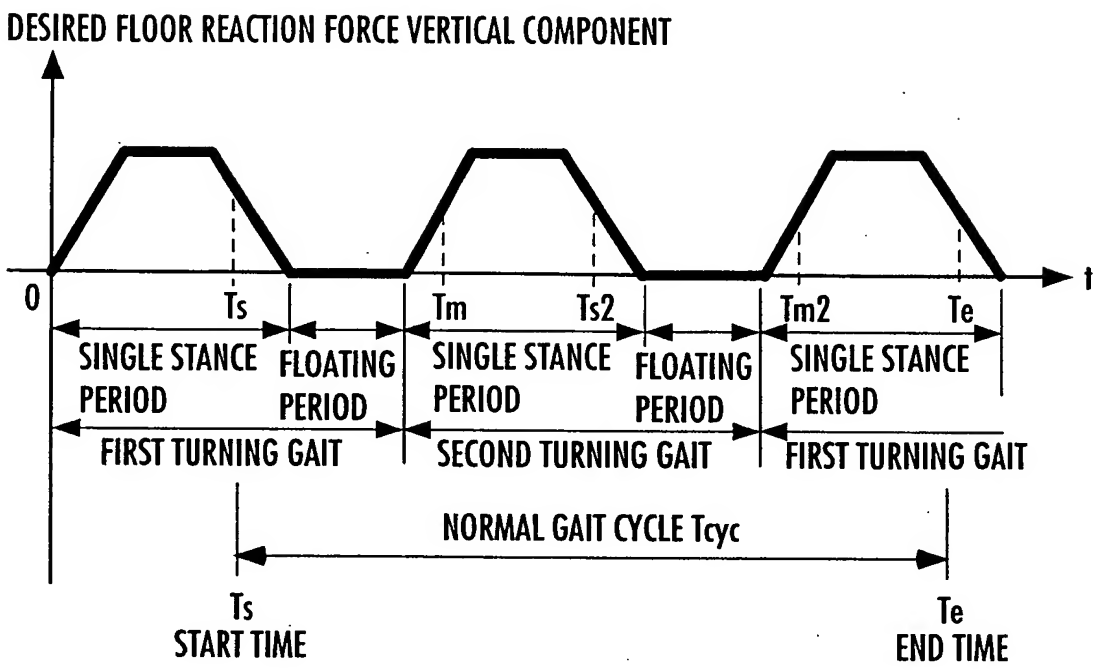

DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT
0
Ts
Tm
Ts2
Tm2
Te
t
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.20

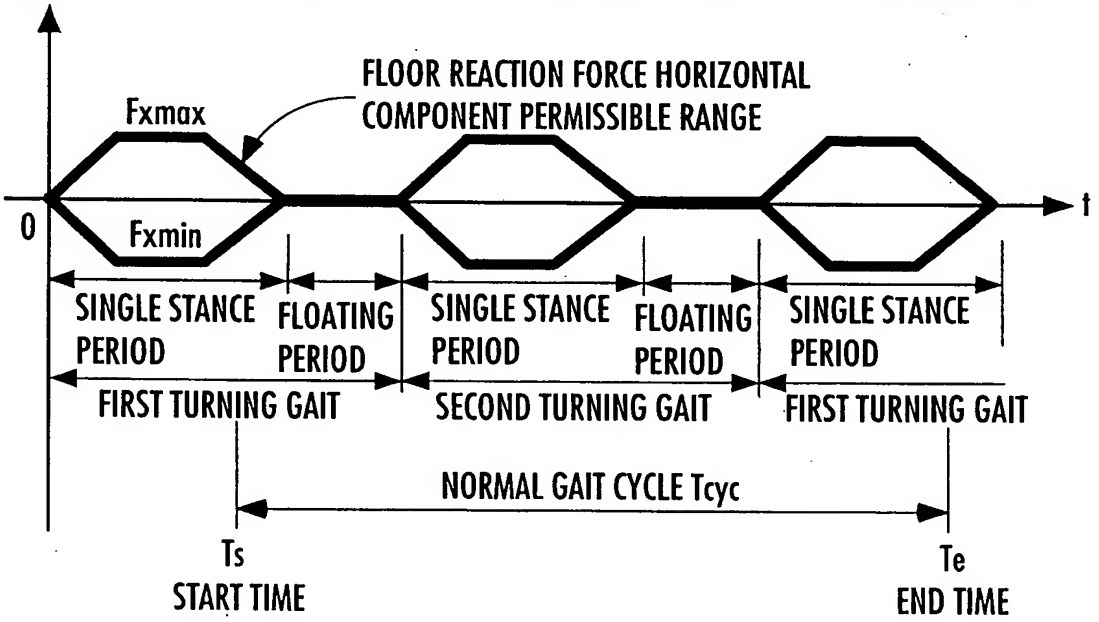

FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Fxmin AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Fxmax
FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE
Fxmax
Fxmin
0
t
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.21

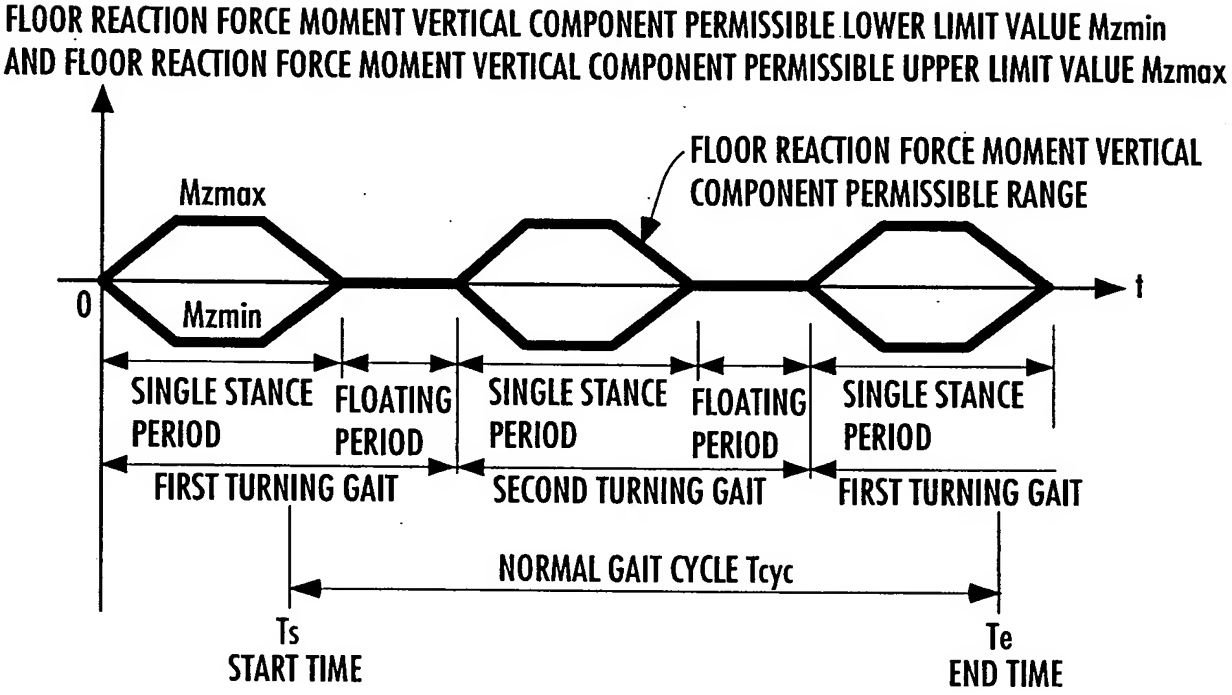

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Mzmin AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Mzmax
FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE
Mzmax
Mzmin
0
t
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.22

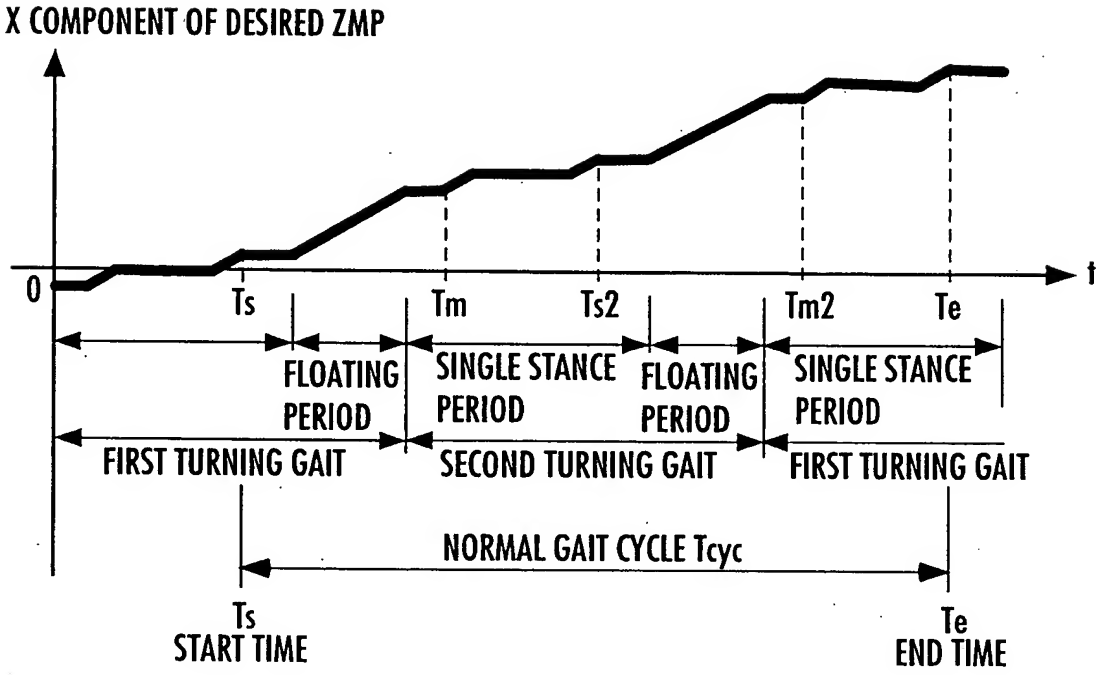

X COMPONENT OF DESIRED ZMP
0
t
Ts
Tm
Ts2
Tm2
Te
FLOATING PERIOD
SINGLE STANCE PERIOD
FLOATING PERIOD
SINGLE STANCE PERIOD
FIRST TURNING GAIT
SECOND TURNING GAIT
FIRST TURNING GAIT
NORMAL GAIT CYCLE Tcyc
Ts
START TIME
Te
END TIME

FIG.23

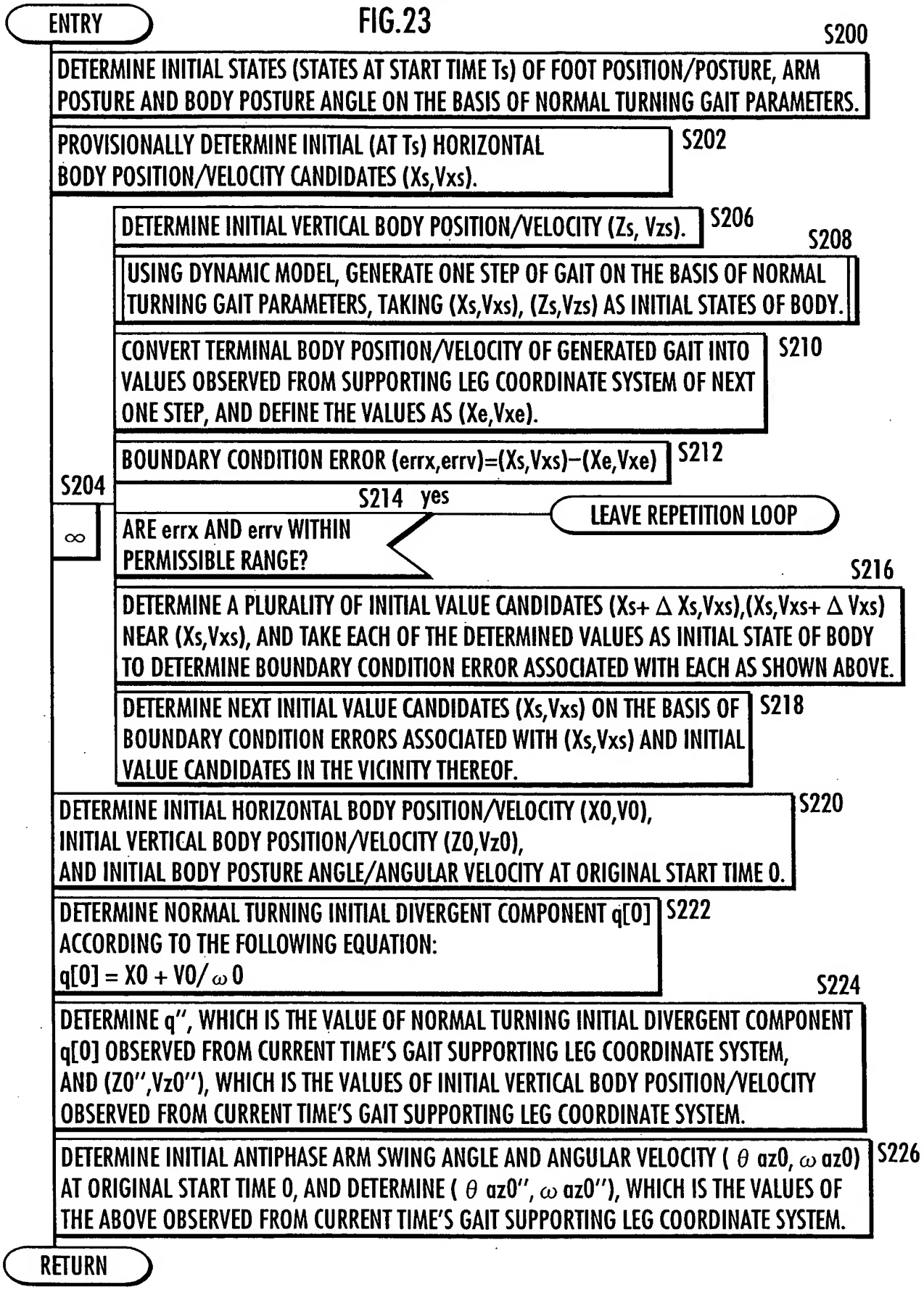

ENTRY
S200
DETERMINE INITIAL STATES (STATES AT START TIME Ts) OF FOOT POSITION/POSTURE, ARM POSTURE AND BODY POSTURE ANGLE ON THE BASIS OF NORMAL TURNING GAIT PARAMETERS.
PROVISIONALLY DETERMINE INITIAL (AT Ts) HORIZONTAL BODY POSITION/VELOCITY CANDIDATES (Xs,Vxs).
S202
DETERMINE INITIAL VERTICAL BODY POSITION/VELOCITY (Zs, Vzs).
S206
S208
USING DYNAMIC MODEL, GENERATE ONE STEP OF GAIT ON THE BASIS OF NORMAL TURNING GAIT PARAMETERS, TAKING (Xs,Vxs), (Zs,Vzs) AS INITIAL STATES OF BODY.
CONVERT TERMINAL BODY POSITION/VELOCITY OF GENERATED GAIT INTO VALUES OBSERVED FROM SUPPORTING LEG COORDINATE SYSTEM OF NEXT ONE STEP, AND DEFINE THE VALUES AS (Xe,Vxe).
S210
BOUNDARY CONDITION ERROR (errx,errv)=(Xs,Vxs)−(Xe,Vxe)
S212
S204
∞
S214 yes
ARE errx AND errv WITHIN PERMISSIBLE RANGE?
LEAVE REPETITION LOOP
S216
DETERMINE A PLURALITY OF INITIAL VALUE CANDIDATES (Xs+ Δ Xs,Vxs),(Xs,Vxs+ Δ Vxs) NEAR (Xs,Vxs), AND TAKE EACH OF THE DETERMINED VALUES AS INITIAL STATE OF BODY TO DETERMINE BOUNDARY CONDITION ERROR ASSOCIATED WITH EACH AS SHOWN ABOVE.
DETERMINE NEXT INITIAL VALUE CANDIDATES (Xs,Vxs) ON THE BASIS OF BOUNDARY CONDITION ERRORS ASSOCIATED WITH (Xs,Vxs) AND INITIAL VALUE CANDIDATES IN THE VICINITY THEREOF.
S218
DETERMINE INITIAL HORIZONTAL BODY POSITION/VELOCITY (X0,V0), INITIAL VERTICAL BODY POSITION/VELOCITY (Z0,Vz0), AND INITIAL BODY POSTURE ANGLE/ANGULAR VELOCITY AT ORIGINAL START TIME 0.
S220
DETERMINE NORMAL TURNING INITIAL DIVERGENT COMPONENT q[0] ACCORDING TO THE FOLLOWING EQUATION:
q[0] = X0 + V0/ω0
S222
S224
DETERMINE q'', WHICH IS THE VALUE OF NORMAL TURNING INITIAL DIVERGENT COMPONENT q[0] OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM, AND (Z0'',Vz0''), WHICH IS THE VALUES OF INITIAL VERTICAL BODY POSITION/VELOCITY OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM.
DETERMINE INITIAL ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY ( θ az0, ω az0) AT ORIGINAL START TIME 0, AND DETERMINE ( θ az0'', ω az0''), WHICH IS THE VALUES OF THE ABOVE OBSERVED FROM CURRENT TIME'S GAIT SUPPORTING LEG COORDINATE SYSTEM.
S226
RETURN

FIG.24

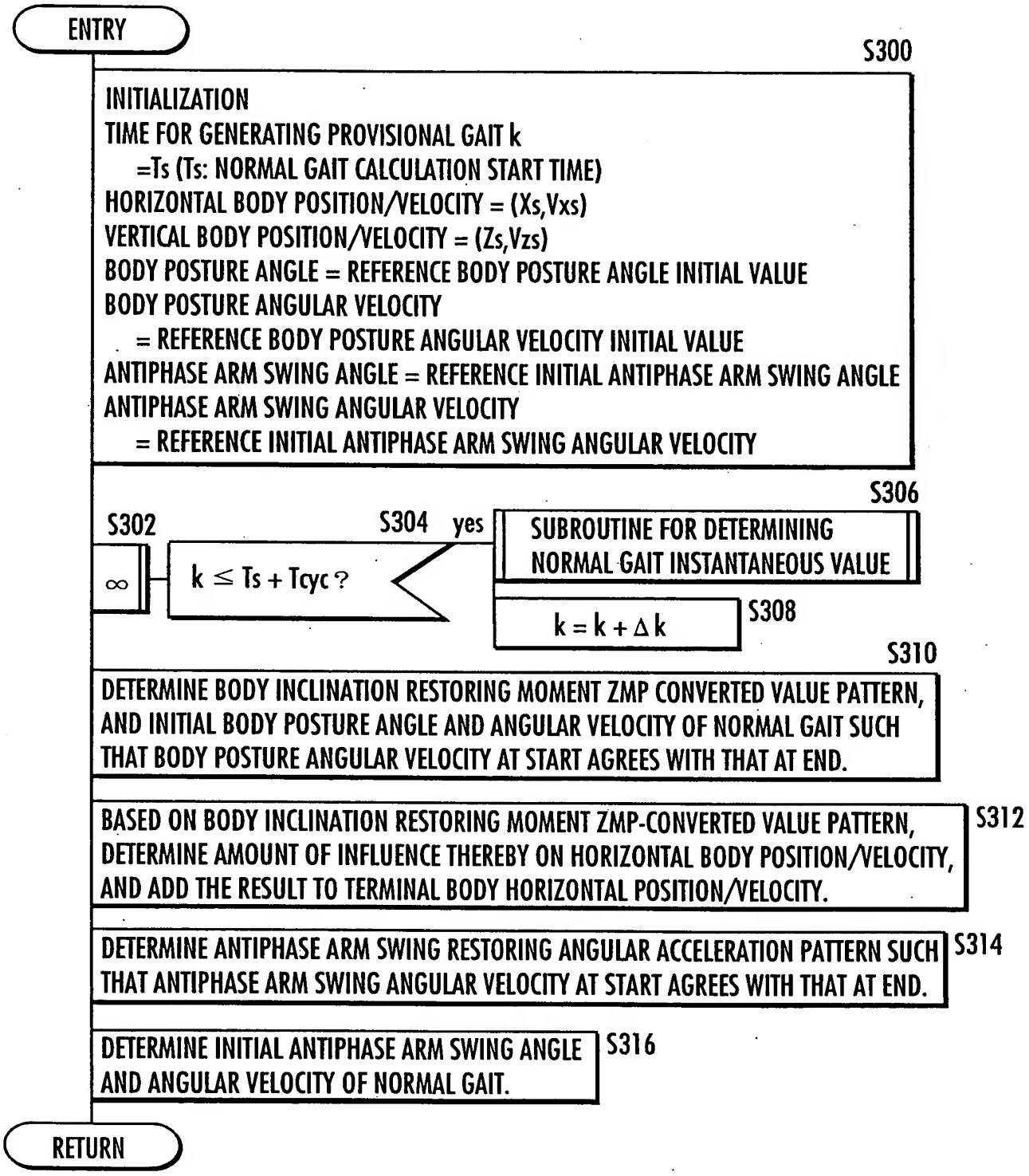

ENTRY
S300
INITIALIZATION
TIME FOR GENERATING PROVISIONAL GAIT k
=Ts (Ts: NORMAL GAIT CALCULATION START TIME)
HORIZONTAL BODY POSITION/VELOCITY = (Xs,Vxs)
VERTICAL BODY POSITION/VELOCITY = (Zs,Vzs)
BODY POSTURE ANGLE = REFERENCE BODY POSTURE ANGLE INITIAL VALUE
BODY POSTURE ANGULAR VELOCITY
= REFERENCE BODY POSTURE ANGULAR VELOCITY INITIAL VALUE
ANTIPHASE ARM SWING ANGLE = REFERENCE INITIAL ANTIPHASE ARM SWING ANGLE
ANTIPHASE ARM SWING ANGULAR VELOCITY
= REFERENCE INITIAL ANTIPHASE ARM SWING ANGULAR VELOCITY
S306
S302
S304
yes
SUBROUTINE FOR DETERMINING NORMAL GAIT INSTANTANEOUS VALUE
∞
k ≤ Ts + Tcyc ?
k = k + Δk
S308
S310
DETERMINE BODY INCLINATION RESTORING MOMENT ZMP CONVERTED VALUE PATTERN, AND INITIAL BODY POSTURE ANGLE AND ANGULAR VELOCITY OF NORMAL GAIT SUCH THAT BODY POSTURE ANGULAR VELOCITY AT START AGREES WITH THAT AT END.
BASED ON BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN, DETERMINE AMOUNT OF INFLUENCE THEREBY ON HORIZONTAL BODY POSITION/VELOCITY, AND ADD THE RESULT TO TERMINAL BODY HORIZONTAL POSITION/VELOCITY.
S312
DETERMINE ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN SUCH THAT ANTIPHASE ARM SWING ANGULAR VELOCITY AT START AGREES WITH THAT AT END.
S314
DETERMINE INITIAL ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY OF NORMAL GAIT.
S316
RETURN

FIG.25

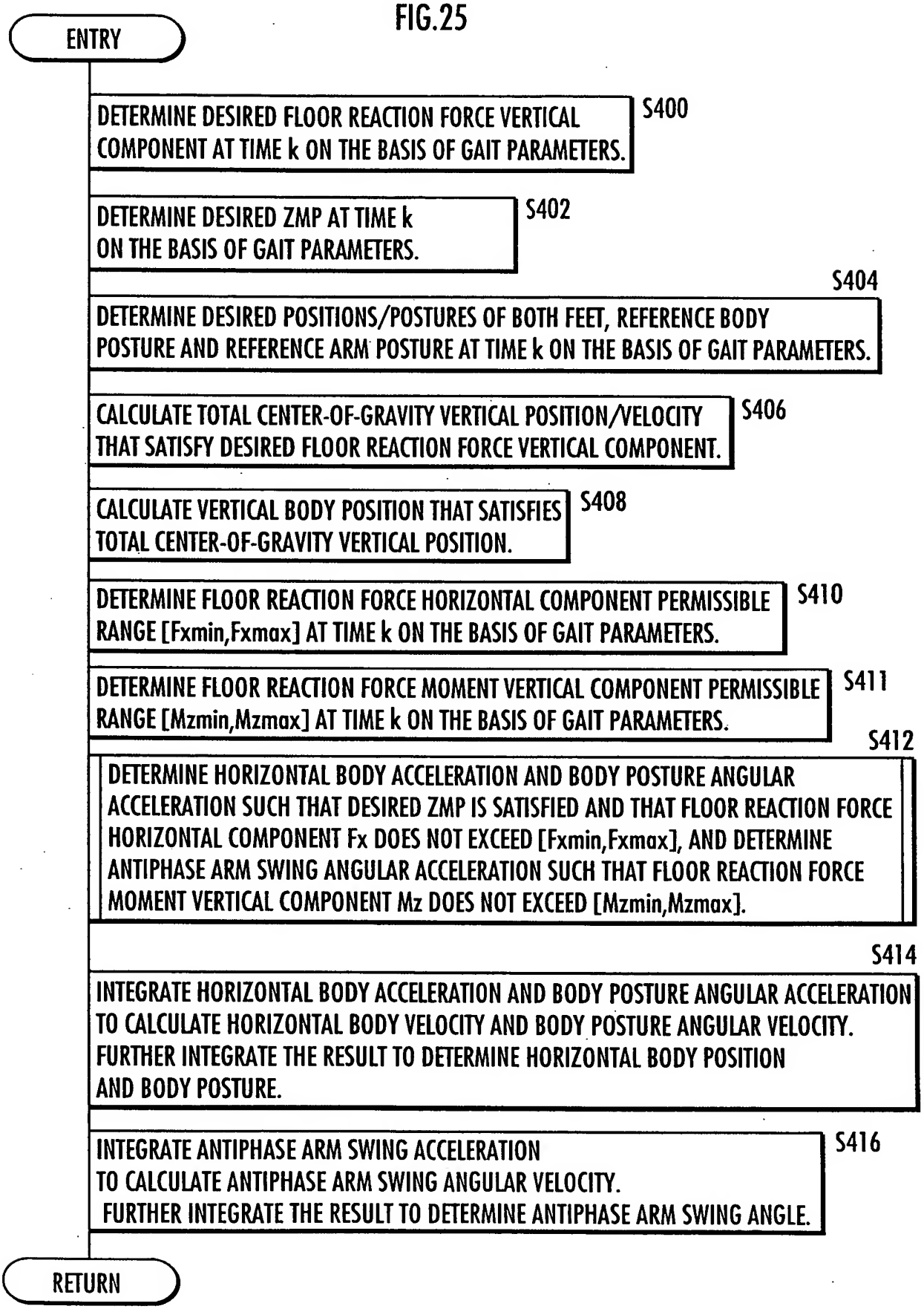

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S400
DETERMINE DESIRED ZMP AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S402
S404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT TIME k ON THE BASIS OF GAIT PARAMETERS.
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFY DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S406
CALCULATE VERTICAL BODY POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S408
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S410
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT TIME k ON THE BASIS OF GAIT PARAMETERS.
S411
S412
DETERMINE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT DESIRED ZMP IS SATISFIED AND THAT FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin,Fxmax], AND DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz DOES NOT EXCEED [Mzmin,Mzmax].
S414
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
S416
RETURN

FIG.26

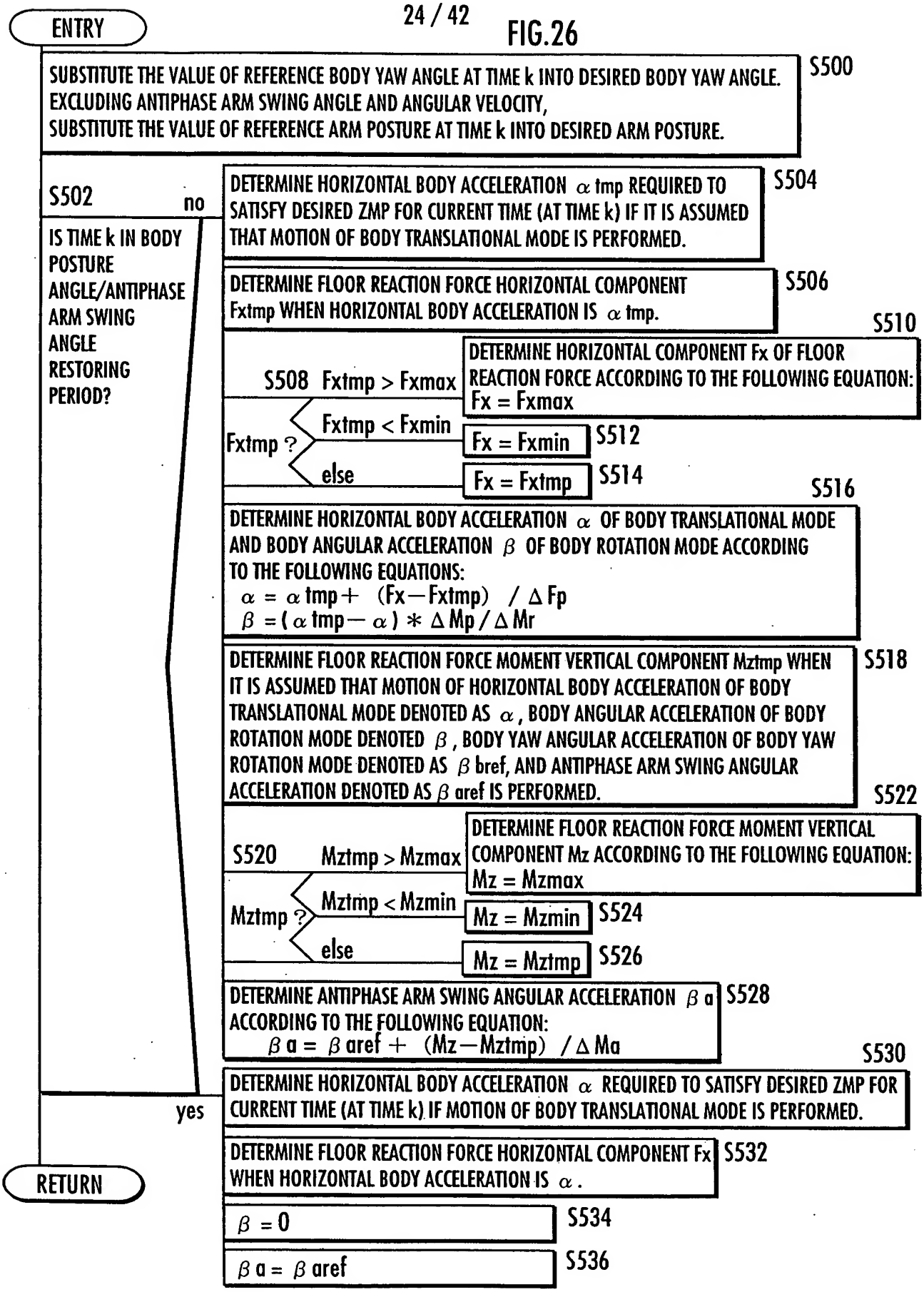

ENTRY
SUBSTITUTE THE VALUE OF REFERENCE BODY YAW ANGLE AT TIME k INTO DESIRED BODY YAW ANGLE. EXCLUDING ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY, SUBSTITUTE THE VALUE OF REFERENCE ARM POSTURE AT TIME k INTO DESIRED ARM POSTURE.
S500
S502
IS TIME k IN BODY POSTURE ANGLE/ANTIPHASE ARM SWING ANGLE RESTORING PERIOD?
no
DETERMINE HORIZONTAL BODY ACCELERATION α tmp REQUIRED TO SATISFY DESIRED ZMP FOR CURRENT TIME (AT TIME k) IF IT IS ASSUMED THAT MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
S504
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp WHEN HORIZONTAL BODY ACCELERATION IS α tmp.
S506
S508 Fxtmp > Fxmax
DETERMINE HORIZONTAL COMPONENT Fx OF FLOOR REACTION FORCE ACCORDING TO THE FOLLOWING EQUATION: Fx = Fxmax
S510
Fxtmp ?
Fxtmp < Fxmin
Fx = Fxmin
S512
else
Fx = Fxtmp
S514
DETERMINE HORIZONTAL BODY ACCELERATION α OF BODY TRANSLATIONAL MODE AND BODY ANGULAR ACCELERATION β OF BODY ROTATION MODE ACCORDING TO THE FOLLOWING EQUATIONS:
α = α tmp + (Fx − Fxtmp) / ΔFp
β = (α tmp − α) * ΔMp / ΔMr
S516
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mztmp WHEN IT IS ASSUMED THAT MOTION OF HORIZONTAL BODY ACCELERATION OF BODY TRANSLATIONAL MODE DENOTED AS α, BODY ANGULAR ACCELERATION OF BODY ROTATION MODE DENOTED β, BODY YAW ANGULAR ACCELERATION OF BODY YAW ROTATION MODE DENOTED AS β bref, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION DENOTED AS β aref IS PERFORMED.
S518
S520 Mztmp > Mzmax
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz ACCORDING TO THE FOLLOWING EQUATION: Mz = Mzmax
S522
Mztmp ?
Mztmp < Mzmin
Mz = Mzmin
S524
else
Mz = Mztmp
S526
DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION β a ACCORDING TO THE FOLLOWING EQUATION:
β a = β aref + (Mz − Mztmp) / ΔMa
S528
yes
DETERMINE HORIZONTAL BODY ACCELERATION α REQUIRED TO SATISFY DESIRED ZMP FOR CURRENT TIME (AT TIME k) IF MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
S530
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN HORIZONTAL BODY ACCELERATION IS α.
S532
β = 0
S534
β a = β aref
S536
RETURN

FIG.27

FLOOR REACTION FORCE HORIZONTAL COMPONENT Fxtmp CREATED WITHOUT TAKING PERMISSIBLE RANGE INTO ACCOUNT

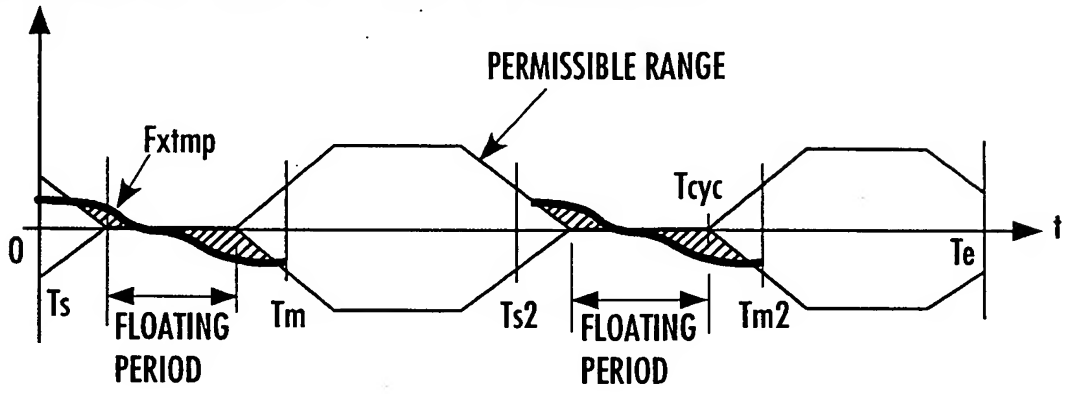



FIG.28

FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx TAKING FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE INTO ACCOUNT

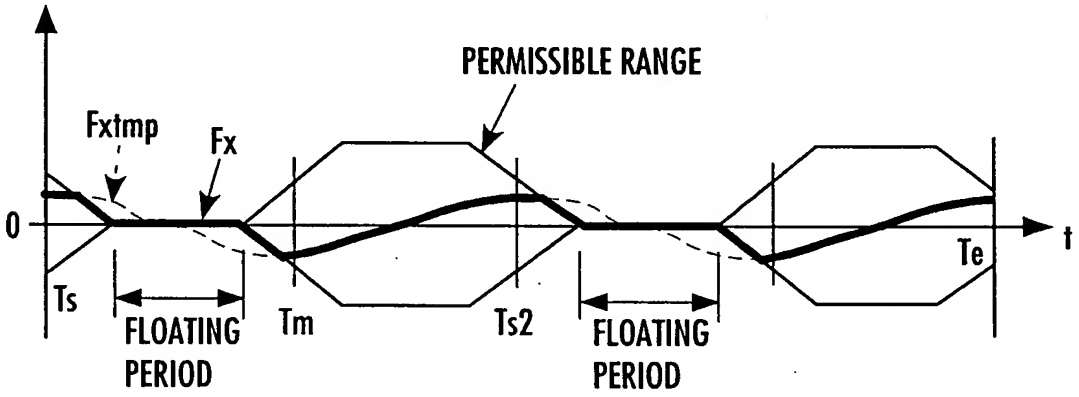



FIG.29

BODY INCLINATION ANGULAR ACCELERATION $\beta$

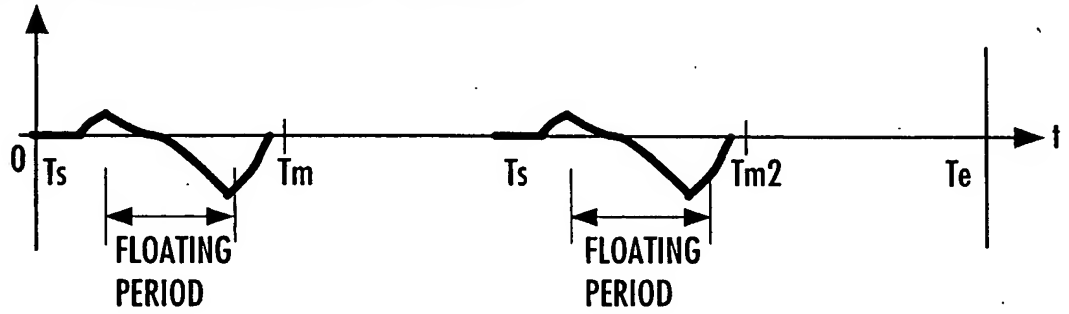


FIG.30

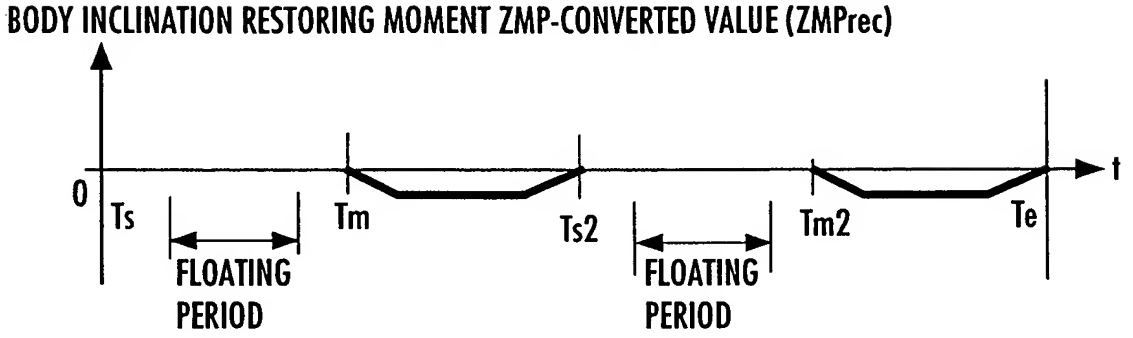

BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE (ZMPrec)
0
Ts
Tm
Ts2
Tm2
Te
t
FLOATING PERIOD
FLOATING PERIOD

FIG.31

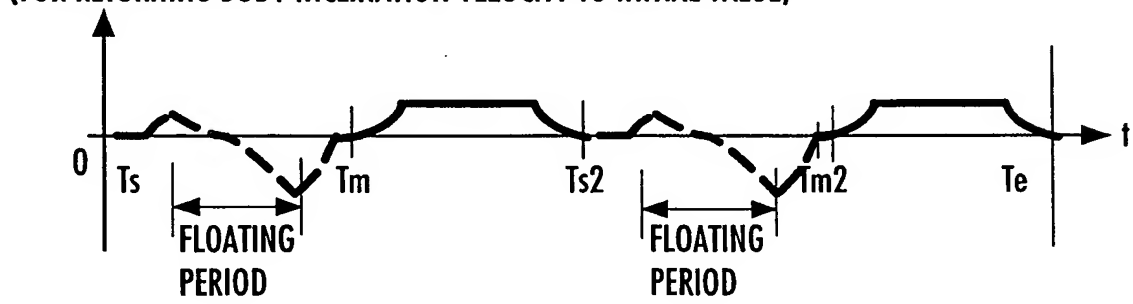

BODY INCLINATION ANGULAR ACCELERATION β
(FOR RETURNING BODY INCLINATION VELOCITY TO INITIAL VALUE)
0
Ts
Tm
Ts2
Tm2
Te
t
FLOATING PERIOD
FLOATING PERIOD

FIG.32

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mztmp CREATED WITHOUT TAKING PERMISSIBLE RANGE INTO ACCOUNT

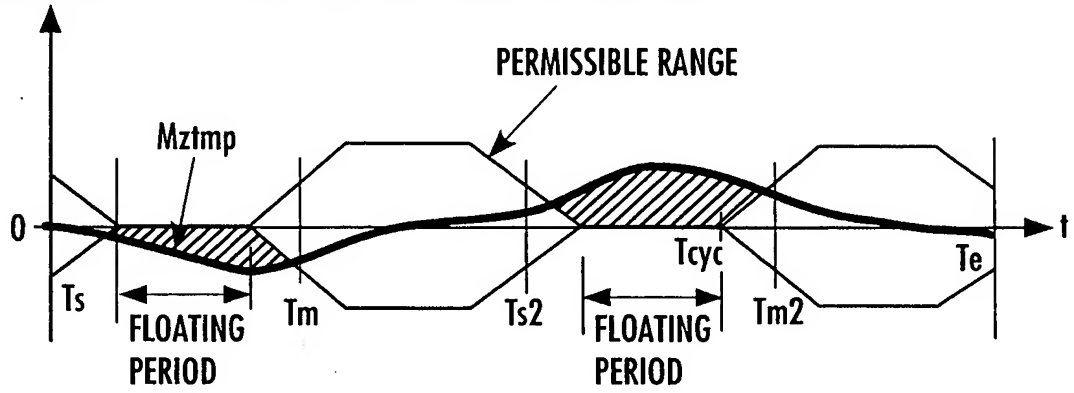



FIG.33

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz TAKING FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE INTO ACCOUNT

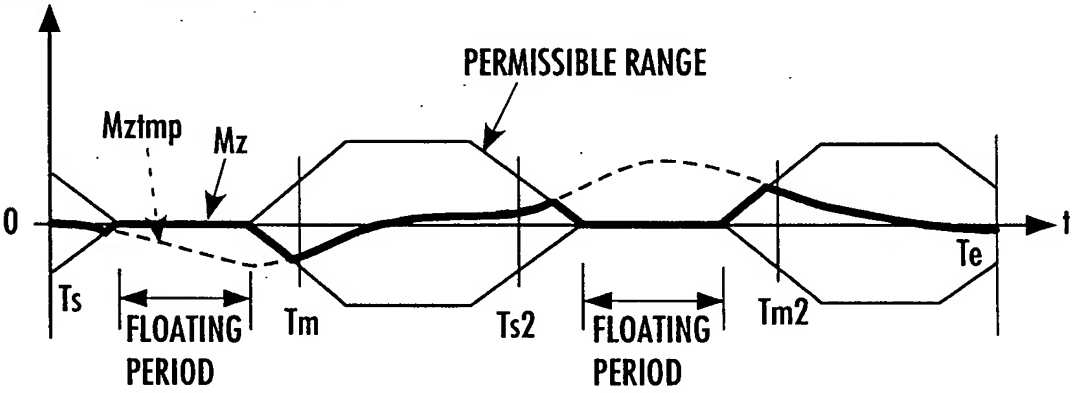



FIG.34

ANTIPHASE ARM SWING MOMENT (Maz)

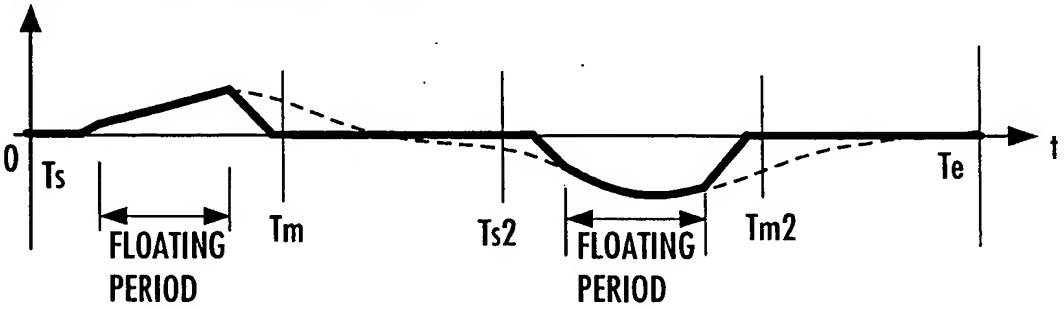


FIG.35

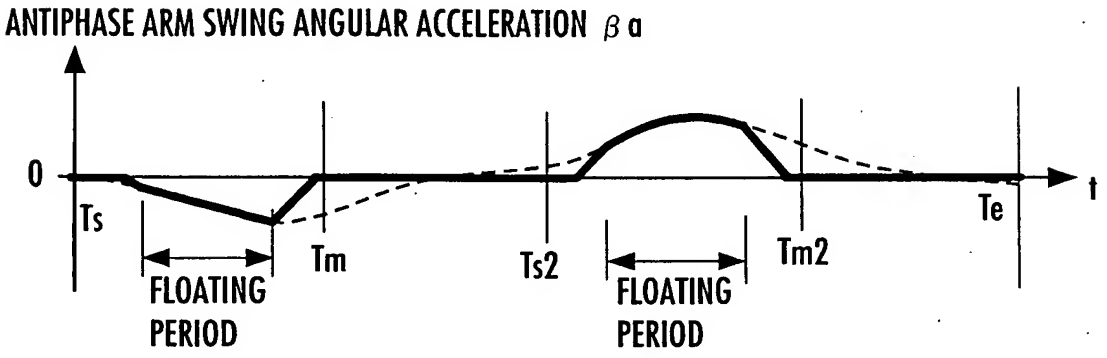



FIG.36

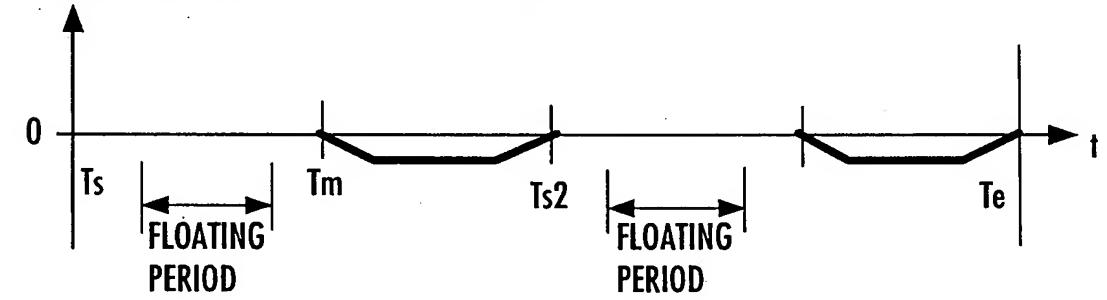



FIG.37

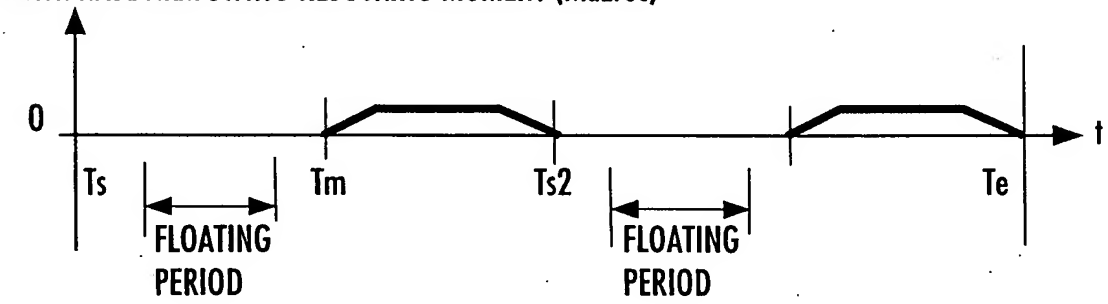


FIG.38

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz
TAKING FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT
PERMISSIBLE RANGE INTO ACCOUNT

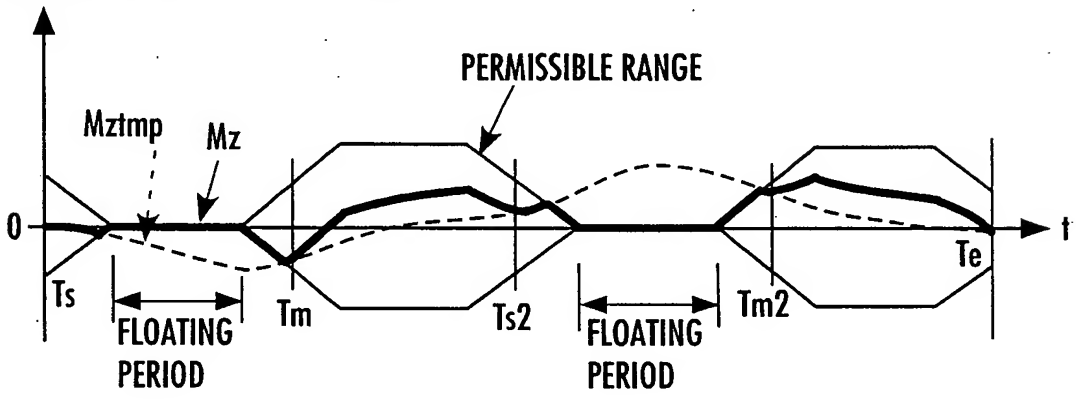


FIG.39

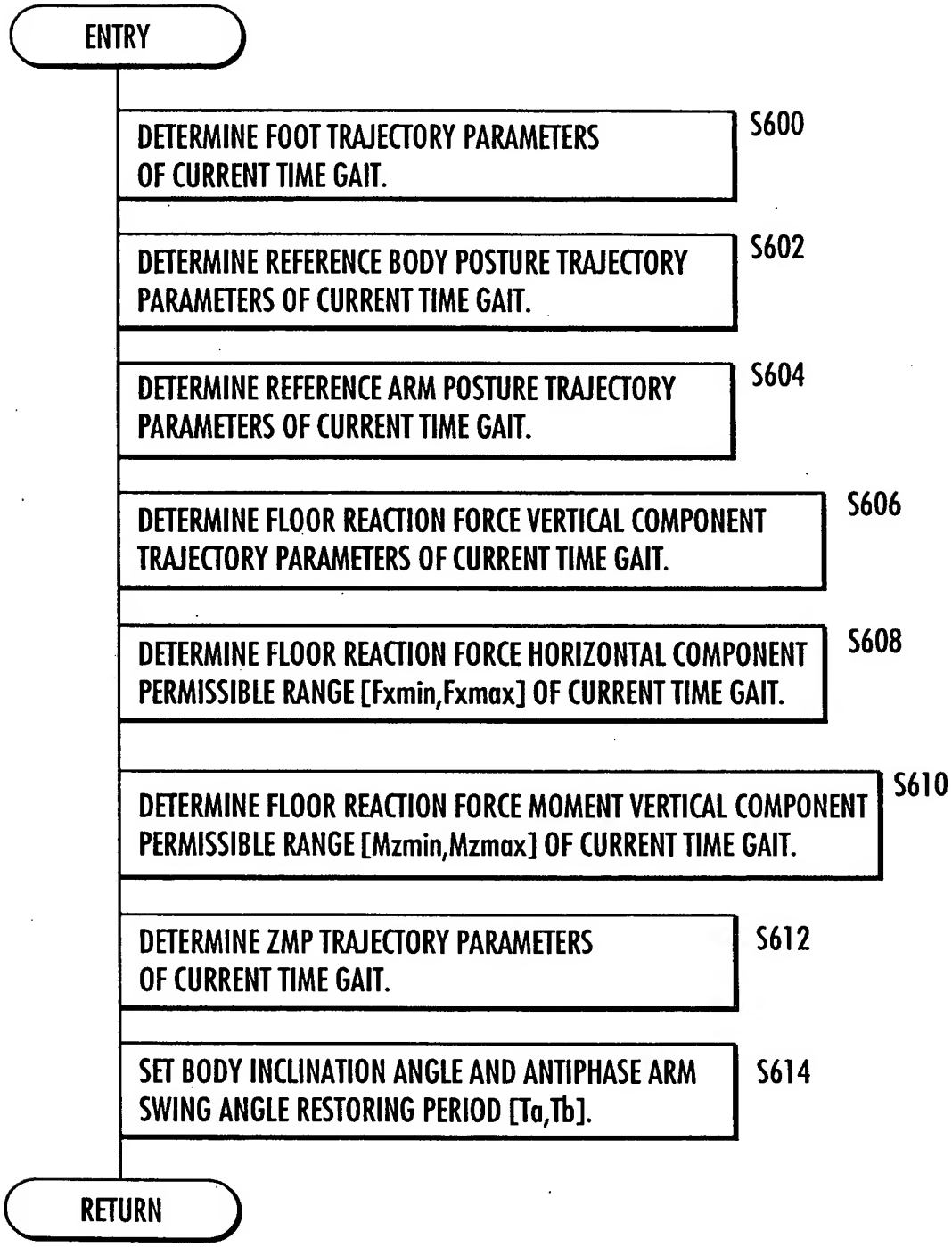

ENTRY
DETERMINE FOOT TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S600
DETERMINE REFERENCE BODY POSTURE TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S602
DETERMINE REFERENCE ARM POSTURE TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S604
DETERMINE FLOOR REACTION FORCE VERTICAL COMPONENT TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S606
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] OF CURRENT TIME GAIT.
S608
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] OF CURRENT TIME GAIT.
S610
DETERMINE ZMP TRAJECTORY PARAMETERS OF CURRENT TIME GAIT.
S612
SET BODY INCLINATION ANGLE AND ANTIPHASE ARM SWING ANGLE RESTORING PERIOD [Ta,Tb].
S614
RETURN

FIG.40

FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Fxmin AND FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Fxmax

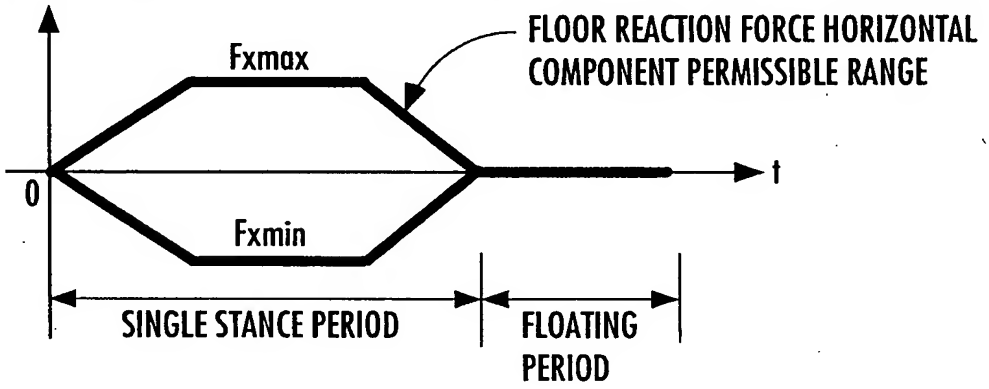


FIG.41

FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE LOWER LIMIT VALUE Mzmin AND FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE UPPER LIMIT VALUE Mzmax

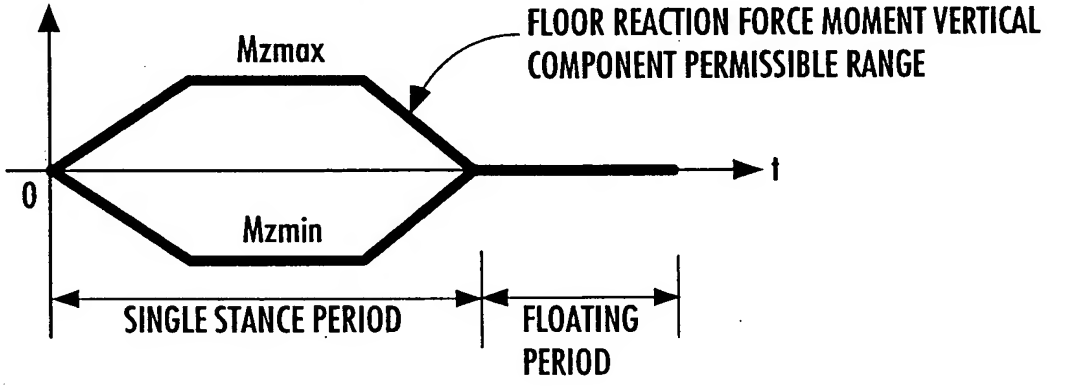


FIG.42

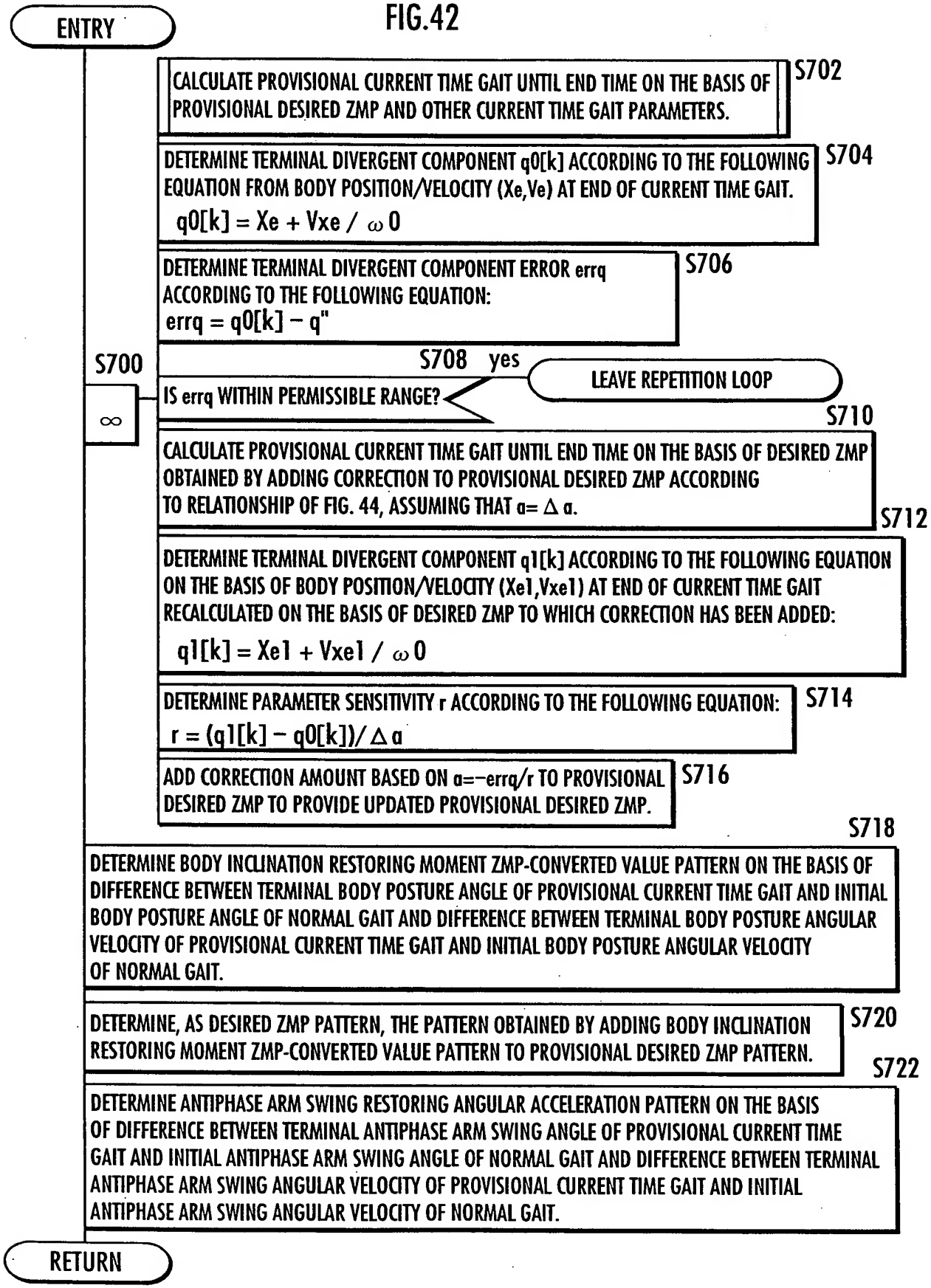

ENTRY
CALCULATE PROVISIONAL CURRENT TIME GAIT UNTIL END TIME ON THE BASIS OF PROVISIONAL DESIRED ZMP AND OTHER CURRENT TIME GAIT PARAMETERS.
S702
DETERMINE TERMINAL DIVERGENT COMPONENT q0[k] ACCORDING TO THE FOLLOWING EQUATION FROM BODY POSITION/VELOCITY (Xe,Ve) AT END OF CURRENT TIME GAIT.
q0[k] = Xe + Vxe / ω0
S704
DETERMINE TERMINAL DIVERGENT COMPONENT ERROR errq ACCORDING TO THE FOLLOWING EQUATION:
errq = q0[k] − q"
S706
S700
∞
S708
IS errq WITHIN PERMISSIBLE RANGE?
yes
LEAVE REPETITION LOOP
S710
CALCULATE PROVISIONAL CURRENT TIME GAIT UNTIL END TIME ON THE BASIS OF DESIRED ZMP OBTAINED BY ADDING CORRECTION TO PROVISIONAL DESIRED ZMP ACCORDING TO RELATIONSHIP OF FIG. 44, ASSUMING THAT α= Δα.
S712
DETERMINE TERMINAL DIVERGENT COMPONENT q1[k] ACCORDING TO THE FOLLOWING EQUATION ON THE BASIS OF BODY POSITION/VELOCITY (Xe1,Vxe1) AT END OF CURRENT TIME GAIT RECALCULATED ON THE BASIS OF DESIRED ZMP TO WHICH CORRECTION HAS BEEN ADDED:
q1[k] = Xe1 + Vxe1 / ω0
DETERMINE PARAMETER SENSITIVITY r ACCORDING TO THE FOLLOWING EQUATION:
r = (q1[k] − q0[k])/Δα
S714
ADD CORRECTION AMOUNT BASED ON α=−errq/r TO PROVISIONAL DESIRED ZMP TO PROVIDE UPDATED PROVISIONAL DESIRED ZMP.
S716
S718
DETERMINE BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN ON THE BASIS OF DIFFERENCE BETWEEN TERMINAL BODY POSTURE ANGLE OF PROVISIONAL CURRENT TIME GAIT AND INITIAL BODY POSTURE ANGLE OF NORMAL GAIT AND DIFFERENCE BETWEEN TERMINAL BODY POSTURE ANGULAR VELOCITY OF PROVISIONAL CURRENT TIME GAIT AND INITIAL BODY POSTURE ANGULAR VELOCITY OF NORMAL GAIT.
DETERMINE, AS DESIRED ZMP PATTERN, THE PATTERN OBTAINED BY ADDING BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN TO PROVISIONAL DESIRED ZMP PATTERN.
S720
S722
DETERMINE ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN ON THE BASIS OF DIFFERENCE BETWEEN TERMINAL ANTIPHASE ARM SWING ANGLE OF PROVISIONAL CURRENT TIME GAIT AND INITIAL ANTIPHASE ARM SWING ANGLE OF NORMAL GAIT AND DIFFERENCE BETWEEN TERMINAL ANTIPHASE ARM SWING ANGULAR VELOCITY OF PROVISIONAL CURRENT TIME GAIT AND INITIAL ANTIPHASE ARM SWING ANGULAR VELOCITY OF NORMAL GAIT.
RETURN

FIG.43

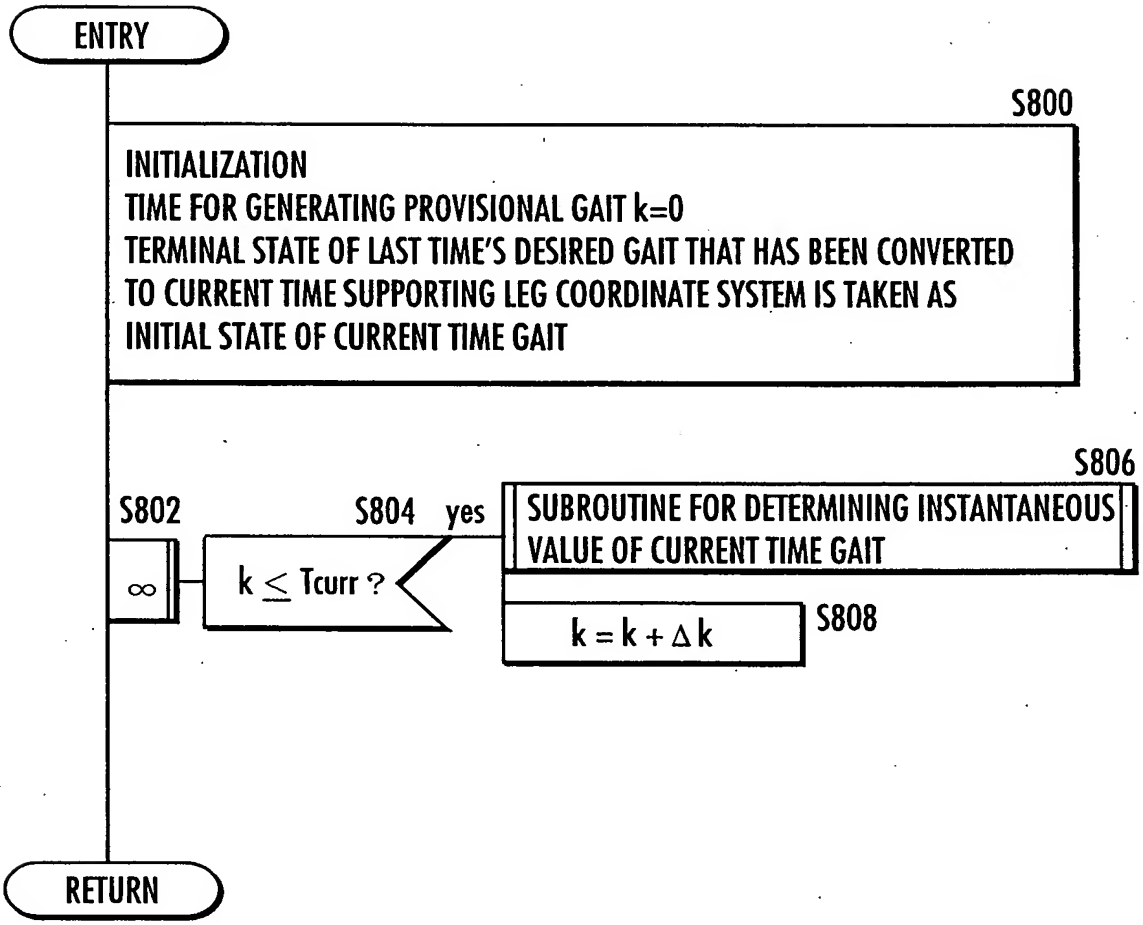

ENTRY
S800
INITIALIZATION
TIME FOR GENERATING PROVISIONAL GAIT k=0
TERMINAL STATE OF LAST TIME'S DESIRED GAIT THAT HAS BEEN CONVERTED TO CURRENT TIME SUPPORTING LEG COORDINATE SYSTEM IS TAKEN AS INITIAL STATE OF CURRENT TIME GAIT
S806
S802
S804
yes
SUBROUTINE FOR DETERMINING INSTANTANEOUS VALUE OF CURRENT TIME GAIT
∞
k ≤ Tcurr ?
k = k + Δk
S808
RETURN

FIG.44

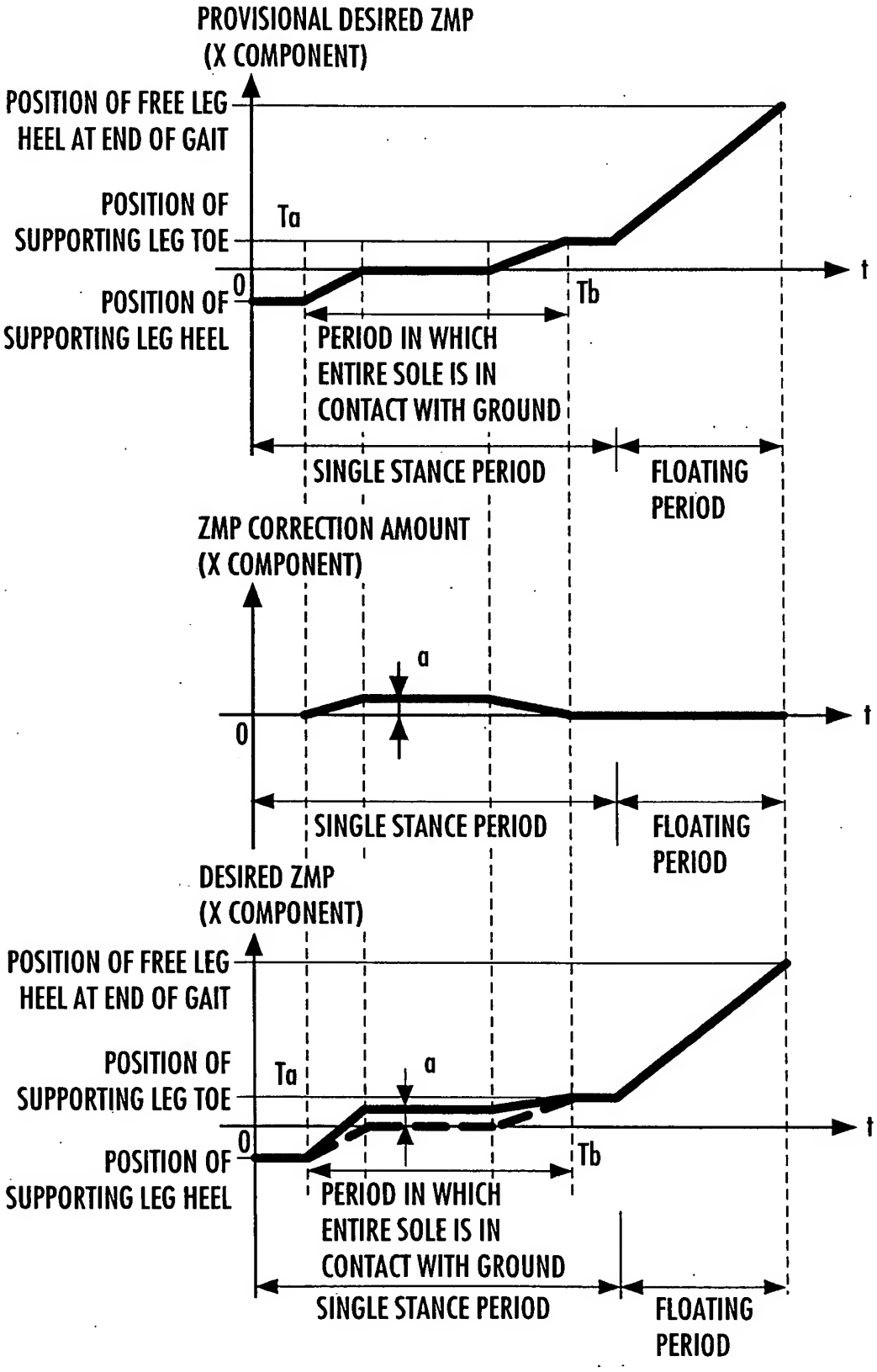

PROVISIONAL DESIRED ZMP
(X COMPONENT)
POSITION OF FREE LEG
HEEL AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
Ta
Tb
0
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD
ZMP CORRECTION AMOUNT
(X COMPONENT)
a
0
t
SINGLE STANCE PERIOD
FLOATING
PERIOD
DESIRED ZMP
(X COMPONENT)
POSITION OF FREE LEG
HEEL AT END OF GAIT
POSITION OF
SUPPORTING LEG TOE
POSITION OF
SUPPORTING LEG HEEL
Ta
a
0
Tb
t
PERIOD IN WHICH
ENTIRE SOLE IS IN
CONTACT WITH GROUND
SINGLE STANCE PERIOD
FLOATING
PERIOD

FIG.45

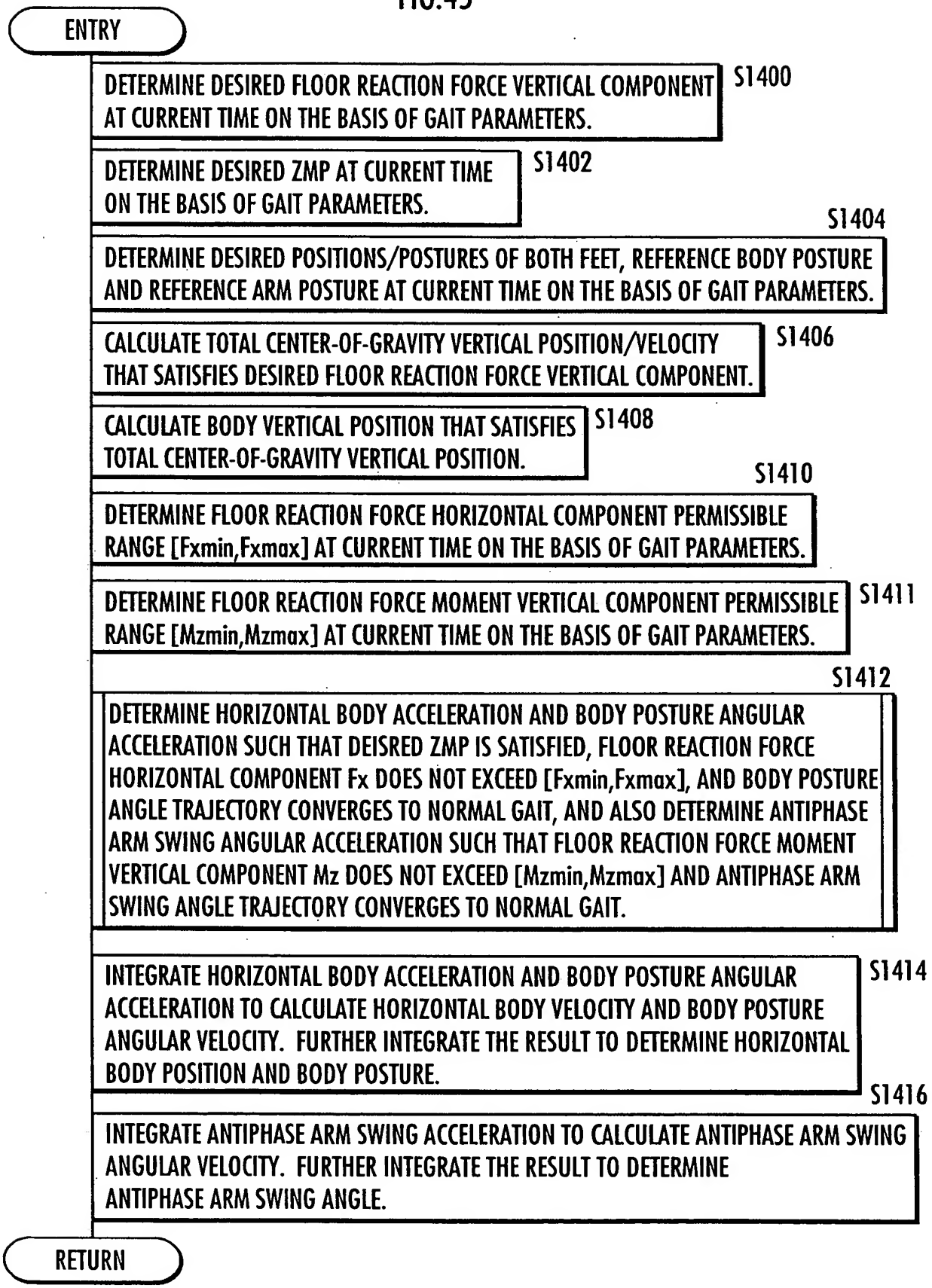

ENTRY
DETERMINE DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1400
DETERMINE DESIRED ZMP AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1402
S1404
DETERMINE DESIRED POSITIONS/POSTURES OF BOTH FEET, REFERENCE BODY POSTURE AND REFERENCE ARM POSTURE AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
CALCULATE TOTAL CENTER-OF-GRAVITY VERTICAL POSITION/VELOCITY THAT SATISFIES DESIRED FLOOR REACTION FORCE VERTICAL COMPONENT.
S1406
CALCULATE BODY VERTICAL POSITION THAT SATISFIES TOTAL CENTER-OF-GRAVITY VERTICAL POSITION.
S1408
S1410
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT PERMISSIBLE RANGE [Fxmin,Fxmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
DETERMINE FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT PERMISSIBLE RANGE [Mzmin,Mzmax] AT CURRENT TIME ON THE BASIS OF GAIT PARAMETERS.
S1411
S1412
DETERMINE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION SUCH THAT DEISRED ZMP IS SATISFIED, FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx DOES NOT EXCEED [Fxmin,Fxmax], AND BODY POSTURE ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT, AND ALSO DETERMINE ANTIPHASE ARM SWING ANGULAR ACCELERATION SUCH THAT FLOOR REACTION FORCE MOMENT VERTICAL COMPONENT Mz DOES NOT EXCEED [Mzmin,Mzmax] AND ANTIPHASE ARM SWING ANGLE TRAJECTORY CONVERGES TO NORMAL GAIT.
INTEGRATE HORIZONTAL BODY ACCELERATION AND BODY POSTURE ANGULAR ACCELERATION TO CALCULATE HORIZONTAL BODY VELOCITY AND BODY POSTURE ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE HORIZONTAL BODY POSITION AND BODY POSTURE.
S1414
S1416
INTEGRATE ANTIPHASE ARM SWING ACCELERATION TO CALCULATE ANTIPHASE ARM SWING ANGULAR VELOCITY. FURTHER INTEGRATE THE RESULT TO DETERMINE ANTIPHASE ARM SWING ANGLE.
RETURN

FIG.46

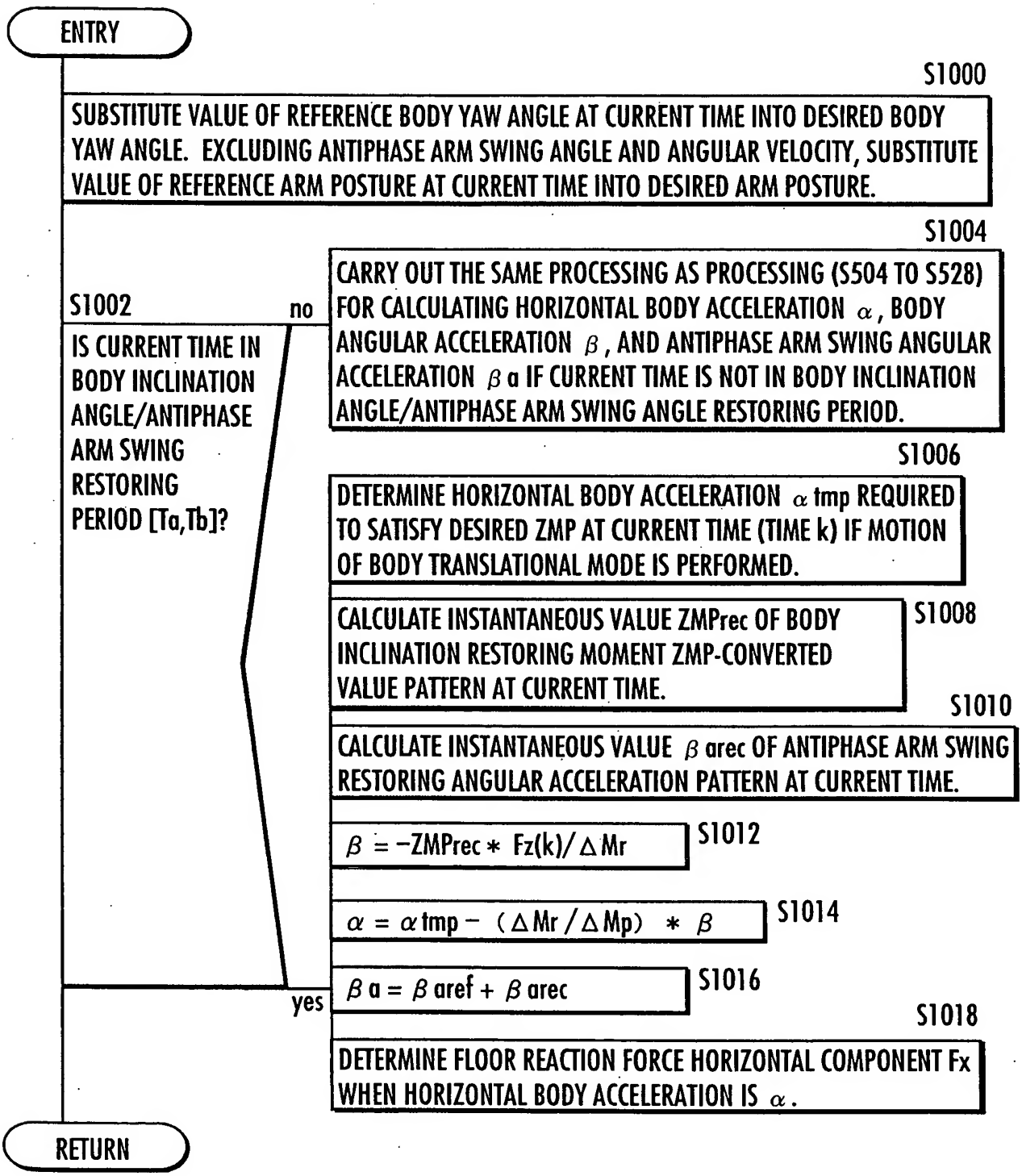

ENTRY
S1000
SUBSTITUTE VALUE OF REFERENCE BODY YAW ANGLE AT CURRENT TIME INTO DESIRED BODY YAW ANGLE. EXCLUDING ANTIPHASE ARM SWING ANGLE AND ANGULAR VELOCITY, SUBSTITUTE VALUE OF REFERENCE ARM POSTURE AT CURRENT TIME INTO DESIRED ARM POSTURE.
S1002
IS CURRENT TIME IN BODY INCLINATION ANGLE/ANTIPHASE ARM SWING RESTORING PERIOD [Ta,Tb]?
no
S1004
CARRY OUT THE SAME PROCESSING AS PROCESSING (S504 TO S528) FOR CALCULATING HORIZONTAL BODY ACCELERATION α, BODY ANGULAR ACCELERATION β, AND ANTIPHASE ARM SWING ANGULAR ACCELERATION βa IF CURRENT TIME IS NOT IN BODY INCLINATION ANGLE/ANTIPHASE ARM SWING ANGLE RESTORING PERIOD.
S1006
DETERMINE HORIZONTAL BODY ACCELERATION α tmp REQUIRED TO SATISFY DESIRED ZMP AT CURRENT TIME (TIME k) IF MOTION OF BODY TRANSLATIONAL MODE IS PERFORMED.
CALCULATE INSTANTANEOUS VALUE ZMPrec OF BODY INCLINATION RESTORING MOMENT ZMP-CONVERTED VALUE PATTERN AT CURRENT TIME.
S1008
S1010
CALCULATE INSTANTANEOUS VALUE β arec OF ANTIPHASE ARM SWING RESTORING ANGULAR ACCELERATION PATTERN AT CURRENT TIME.
β = −ZMPrec * Fz(k)/ΔMr
S1012
α = α tmp − (ΔMr / ΔMp) * β
S1014
yes
βa = β aref + β arec
S1016
S1018
DETERMINE FLOOR REACTION FORCE HORIZONTAL COMPONENT Fx WHEN HORIZONTAL BODY ACCELERATION IS α.
RETURN

FIG.47

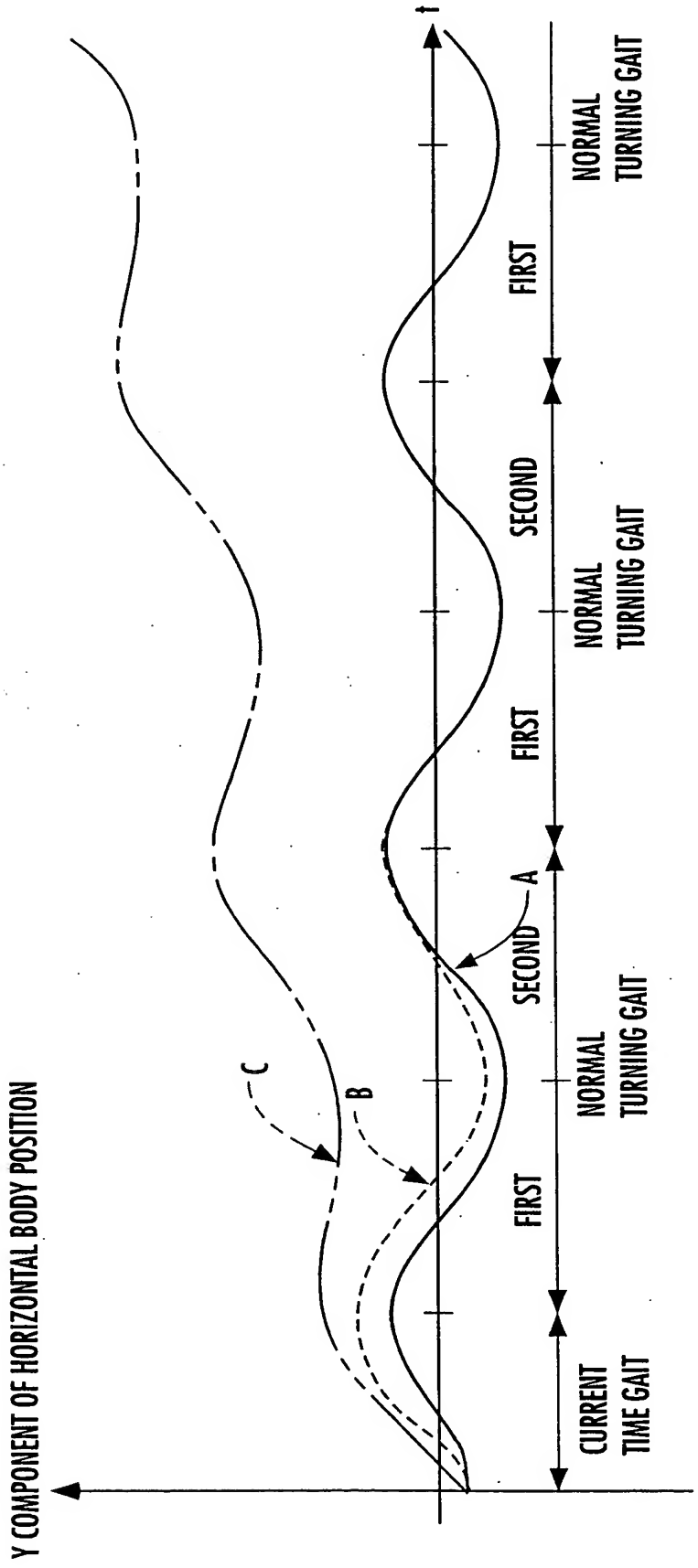

Y COMPONENT OF HORIZONTAL BODY POSITION
t
C
B
A
FIRST
SECOND
NORMAL
TURNING GAIT
CURRENT
TIME GAIT
FIRST
SECOND
NORMAL
TURNING GAIT
FIRST
NORMAL
TURNING GAIT

FIG.48

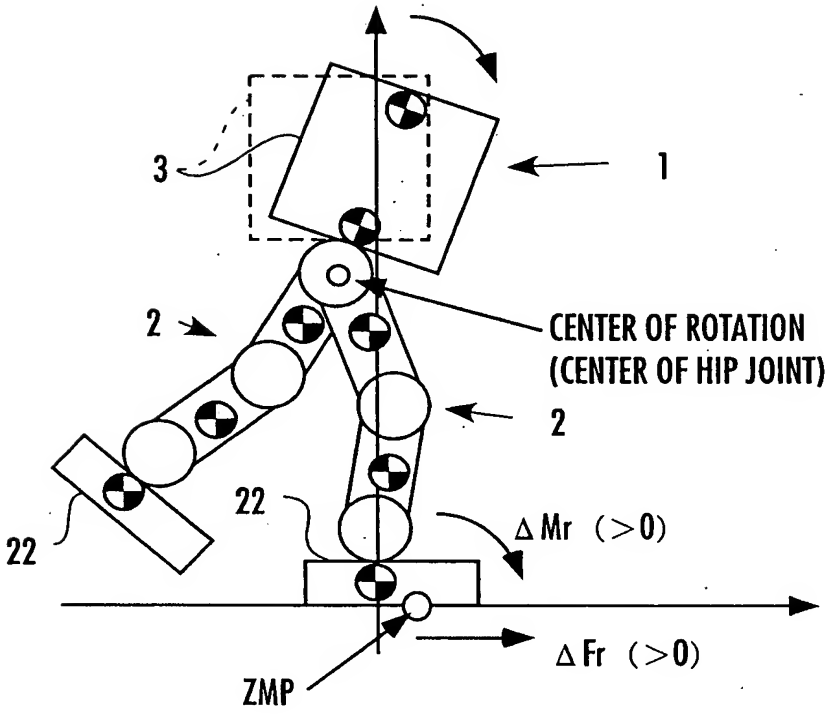

3
1
2
CENTER OF ROTATION
(CENTER OF HIP JOINT)
2
22
22
ΔMr (>0)
ΔFr (>0)
ZMP

FIG.49

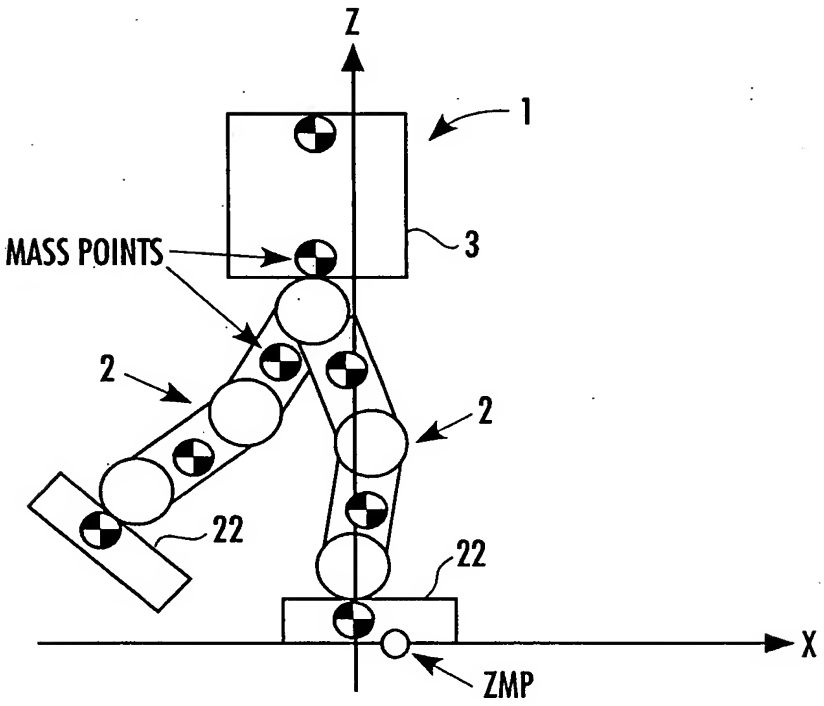


FIG.50

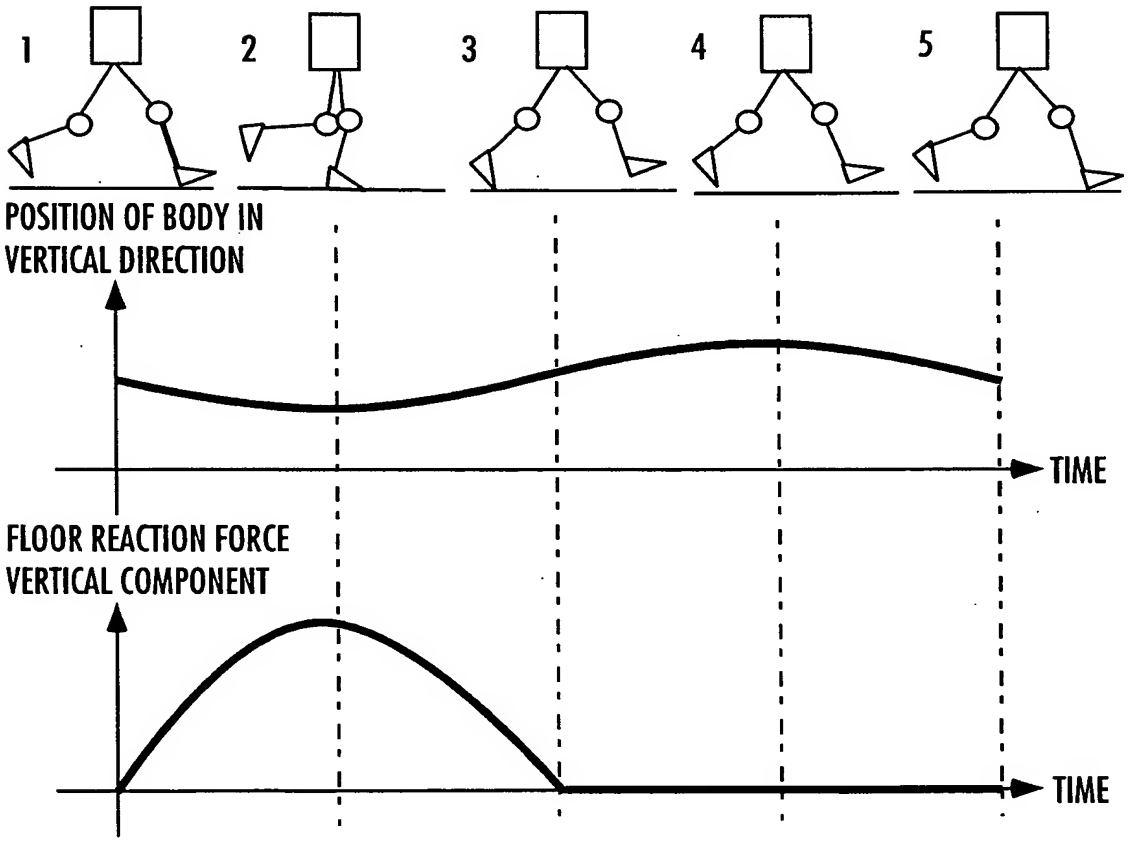
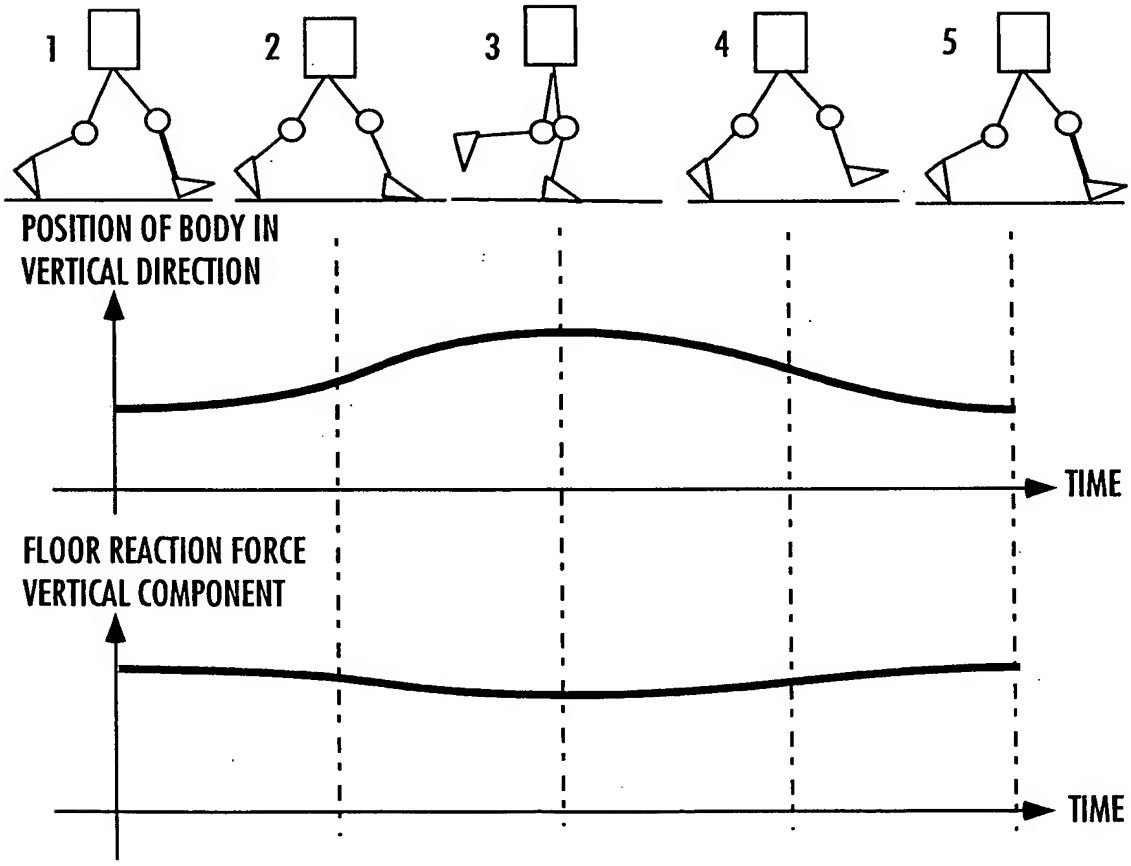

1
2
3
4
5
POSITION OF BODY IN VERTICAL DIRECTION
TIME
FLOOR REACTION FORCE VERTICAL COMPONENT
TIME

FIG.51


1
2
3
4
5
POSITION OF BODY IN VERTICAL DIRECTION
TIME
FLOOR REACTION FORCE VERTICAL COMPONENT
TIME